Fermi National Accelerator Laboratory

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Design Note of a 10,000A, 1,000Vdc Solid State Dump Switch for the Magnet Test Facility

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1. SUMMARY

This report describes the design of a 10,000A/1000Vdc dump switch for the superconducting magnet test program at Fermilab. The switch inserts a dump resistor (Ref. 1) in series with a charged superconducting magnet when a magnet quenches or other faults are detected. The dump resistor dissipates the majority of the magnetically stored energy after the dump switch has opened.

The switch uses 6 parallel inverter type run SCR's which get commutated off via a dump SCR and stored energy in a dump capacitor. Switching time is less then 150×10^{-6}sec. All switch power components are water cooled and mounted in a 72"H x 36" W x 30"D steel enclosure.

The controls have provisions for 8 dump command inputs, with a first fault latch. They also provide reference limit control resulting from SCR turn on failure or unacceptable dump resistor tap selection. Dump failure detection and 24 interlocks are provided. All controls are mounted in a relay rack. Quench detection is provided by the magnet test facility. Two 5000 A power supplies are operated in parallel to provide 10,000 Adc.

2. DESIGN REQUIREMENTS AND CIRCUIT CHOICE

The general design requirements requested by the magnet test facility were as follows:

SWITCH	Solid state, indoor 10,000A, 1000V
CONTROL UPS	None
REDUNDANT CIRCUIT	None
BACK UP	None
CONTROL/RESET	Via power supplies
REMOTE STATUS	Yes
REMOTE DUMP COMMANDS	Closed contact permit

Drawing #ATV052488 shows various possible dump switch schemes in Figs. 1 through 6. The switch arrangements shown in Figs. 2 and 3 do not interrupt the current flow through the power supplies, and thus allow an escape path for the stored energy at the power supply side.

This amount of stored energy can be substantial and it needs to go somewhere. Large capacitors or varistors could be installed to absorb this energy if the escape path is interrupted. Figure 2 and 3 do not have this problem, but need some extra interlocks at the dump resistor to protect against run SCR turn-on failure. Run SCR turn-on failure forces the load current through the dump resistor. The dump switch scheme of Fig. 2 was chosen because of its simplicity.

Other components then SCR's were considered for the switch. They are briefly summarized below.

SCR's	Need 6 in parallel Forward drop ~ 1.6 V Cost $600 each Need stored energy to switch off, ~$4000 total Practical
IGBT's	Need 40 in parallel Forward drop ~3V Cost ~$400 each Low voltage rating Does not need stored energy to switch off Not practical
GTO's	Need ~10 in parallel Forward drop ~2.6V Cost ~$2000 each Needs little stored energy to switch off Expensive, high losses
Mechanical Switches	Need 2 - 5000A switches in parallel Forward drop ~0V Cost ~$7000 each Does not need stored energy to switch off Simple controls Limited life Switching time ~100 m sec A practical cost effective solution, especially for back up

3. CHOOSING THE SWITCH COMPONENTS

The dump switch schematic is shown in its most basic form in Fig. 7.

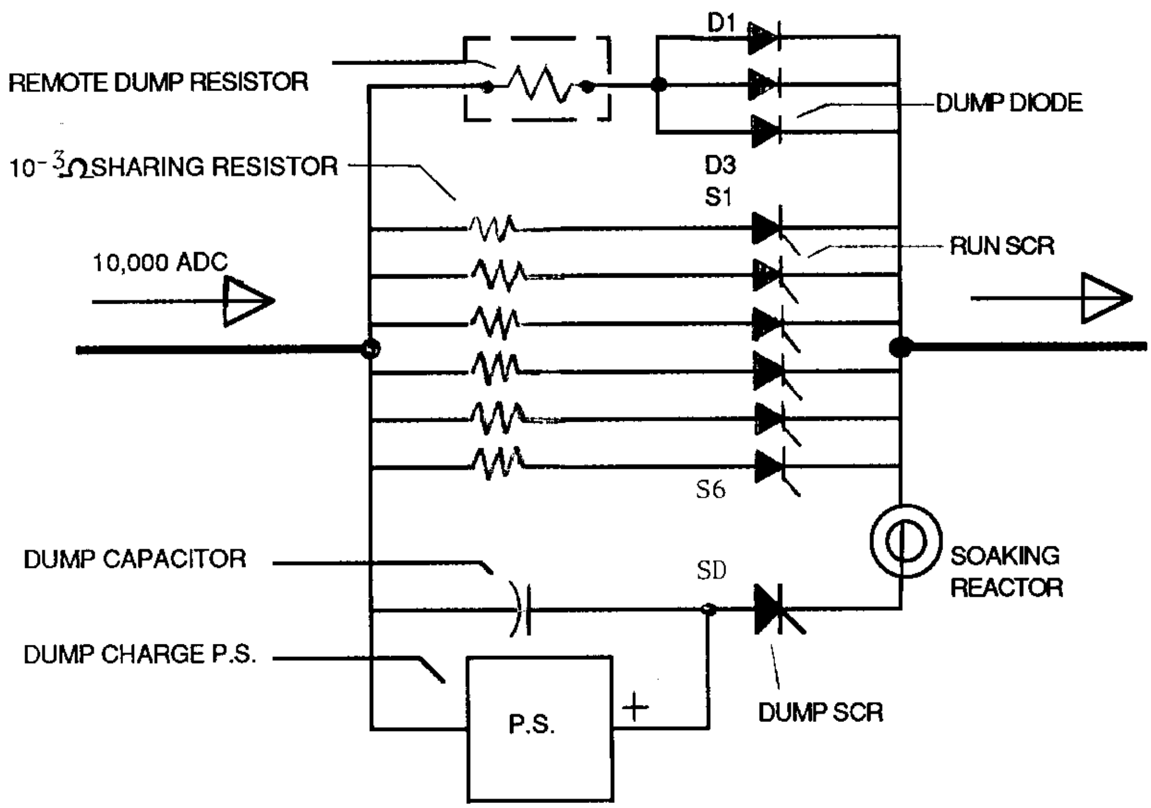


Figure 7. Dump Switch

The run SCR's carry up to 10,000ADC continuous. They get turned off (reverse biased) when the dump SCR releases the stored charge in the dump capacitor. A soaking reactor limits the rate of current rise di/dt through the dump SCR at turn on. There must be enough charge in the dump capacitor to supply a reverse bias across the run SCR's for a period longer than their turn off time. The dump diodes prevent dump capacitor discharge through the dump resistor.

3.1 Run SCR Selection

The run SCR's are mounted at water cooled heatsinks. Several SCR's need to be operated in parallel so they can carry 10,000A total. The run SCR's also should have a short "turn off" time t_q, which is common for inverter type SCR's. Shorter turn-off times allow a smaller dump capacitor choice. Dump capacitors are rather expensive, since they have to withstand the full 1000V dump voltage developed across the external dump resistor. Capacitor size reductions of a factor of two are practical by choosing an inverter SCR (t_q = 100 μs) versus a regular SCR (t_q = 200 μs). Inverter SCR's are somewhat more expensive, but cost savings are still about $3000, not counting the extra volume needed to mount more dump capacitors.

The run SCR's need a voltage rating of about 2000V for a blocking voltage safety factor of 2, at a dump voltage of 1000V. Several inverter SCR's (GE, Westcode, IR) rated 2000 Adc, 1800 V are commercially available. Choosing 6 SCR's in parallel permits mounting them in pairs and allows for some unequal current distribution. Current balancing resistors of $1 \times 10^{-3}\ \Omega$ are installed to force current sharing and enchance turn on of all SCR's. There will always be one SCR that turns on first. The low forward drop across the one SCR makes it difficult for other parallel SCR's to start conduction. The sharing resistor raises the anode to cathode voltage across the non-conducting SCR's and they will all come on before the current in any conducting SCR exceeds 2000 Adc.

The run SCR junction temperature is rated 125°C (IR#88-6563). Calculate the maximum junction temperature as follows:

Thermal resistance junction to case; double side cooling	$R_{\theta J\text{-}C}$ = 0.011 °C/W
Case to sink	$R_{\theta C\text{-}S}$ = 0.006 °C/W
Sink to water	$R_{\theta S\text{-}W}$ = 0.0045 °C/W
Total	$R_{\theta J\text{-}W}$ = 0.0215 °C/W
SCR losses at 2000 A:	2000 x 1.65 = 3300 W
SCR junction temperature rise:	3300 x 0.0215 = 71°C

The cooling water runs in series through the SCR's and arrives at the last SCR at 51°C with an inlet water temperature of 40°C. The maximum SCR junction temperature would therefore be 71 + 51 = 122°C. This is a rather conservative estimate because each SCR runs in reality at about 1700 Adc maximum.

3.2 Dump SCR Selection

The dump SCR can be a regular SCR rated for high di/dt and 2000 V. The dump SCR needs to handle the dump current to force commutation of the run SCR's and must also carry the reverse charging current into the dump capacitor. The dump current out of dump capacitor could last 400 μsec at 10,000 A, when a dump charge safety margin of 4 is used. Reverse charging could take another 400 μsec, so the dump SCR current may be approximated by a 10,000 A square wave pulse that lasts 1 m sec (Fig. 8).

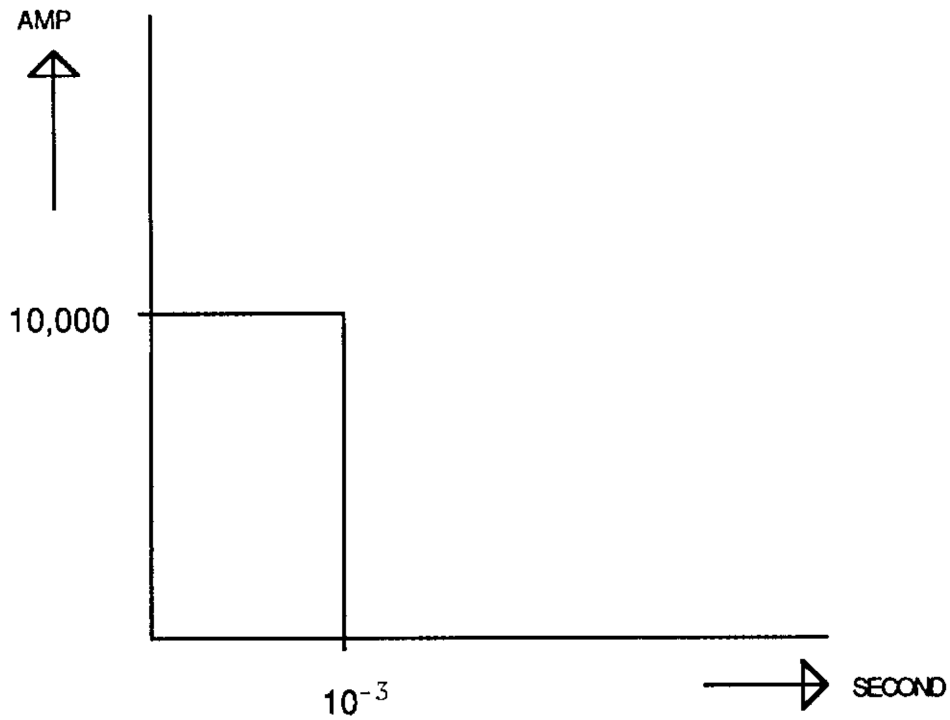


Fig. 8. Dump SCR current pulse used for junction temperature estimates.

SCR #IR S77R18A is used as the dump SCR. The forward drop at 10,000 A is 1.55 V resulting in 15,500 W losses for a duration of 1 m sec. The junction temperature rise can now be calculated as follows:

Transient thermal impedance $R_{\theta J\text{-}C}$ at 1 m sec is: 0.00045 $^{o}C/W$

$\Delta T = 0.00045 \times 15{,}500 = 7^{o}C$

The junction temperature is 51 + 7 = 58°C after a dump. The rated junction temperature is 125°C.

3.3 Dump Diode Selection

The dump diodes must be able to withstand large exponentially decaying current pulses, because a large variety of load and dump resistor combinations are possible. The worst dump pulse could be a 10,000 A pulse, exponentially decaying with a 0.5 sec. time constant. This approaches almost DC operation as far as the dump diode operating temperature is concerned. It may be prudent to use the long duration thermal impedance for junction temperature calculation, to cover for unforeseen dump current pulses. This approach would require about a 30% dump diode rating increase, and probably does not cost much more.

Choose therefore the long term thermal impedance to calculate the dump diode junction temperature. Packaging is simpler using one or three dump diodes. One dump diode cannot handle a 10,000 A pulse, so we will choose 3. The maximum current pulse would be 3500 A peak, to allow for some imbalance. The diode used is Marconi #DS2103 SW20, rated 2000 V, 5700 A RMS. This is a very big diode but it was more competatively priced than the smaller specified 77 mm units.

Calculate the junction temperature rise as follows:

Losses are 1.2 V x 3500 A	4200 W
Thermal impedance	$R_{\theta J\text{-}C} = 0.0115\ ^{o}C/W$
Thermal impedance	$R_{\theta C\text{-}W} = 0.005\ ^{o}C/W$
The junction temperature rise is:	4200 x 0.0165 = 70°C

The maximum junction temperature with 40°C water would be 110°C. The rated junction temperature is 175°C blocking and 200°C conducting. Three diodes are more than adequate.

3.4 General Solid State Component Choice Comment

All SCR's and diodes are choosen to fit the same size watercooled heatsink and mounting clamp. They can all use the same mounting force. This simplifies mechanical packaging. Each SCR and diode is equiped with a snubber for transient suppression. The forward drop of parallel SCR's or parallel diodes does not need matching.

3.5 Design of the Current Sharing Resistors for the Run SCR's

The sharing resistors are used to force current balancing and also SCR turn on below 2000 A per SCR maximum operating current. A $1 \times 10^{-3}\ \Omega$ sharing resistor yields a maximum voltage drop of 2V at 2000A across the resistor in addition to a 1.6V drop across the SCR. This total voltage drop of 3.6 V should be enough for other parallel SCR's to turn on. The sharing resistor is therefore chosen to be $1 \times 10^{-3}\ \Omega$ at 20°C. It is made from 304 stainless steel pipe, 3/4", 11 gage, 0.8074 lbs/ft A 12" long piece of 1 inch^2 stainless steel has a resistance of $0.34 \times 10^{-3}\ \Omega$ at 20°C and weighs 3.4 lbs.

The length needed for $1 \times 10^{-3}\ \Omega$ is therefore:

$$\frac{L}{12} \times \frac{3.4}{0.8074} \times 0.34 \times 10^{-3} = 10^{-3}\Omega$$

$$L = 8.4''$$

A final pipe length of 10" was used to make the resistors, because the material was measured at $10^{-3}\ \Omega$ for a 10" length. Drawing ATV040389 MTF (Sheets 1,2 and 3) shows the water cooled sharing resistors with brazed on flags to connect them to the heatsinks and power bus.

3.6 Design of the Soaking Reactor for the Dump SCR

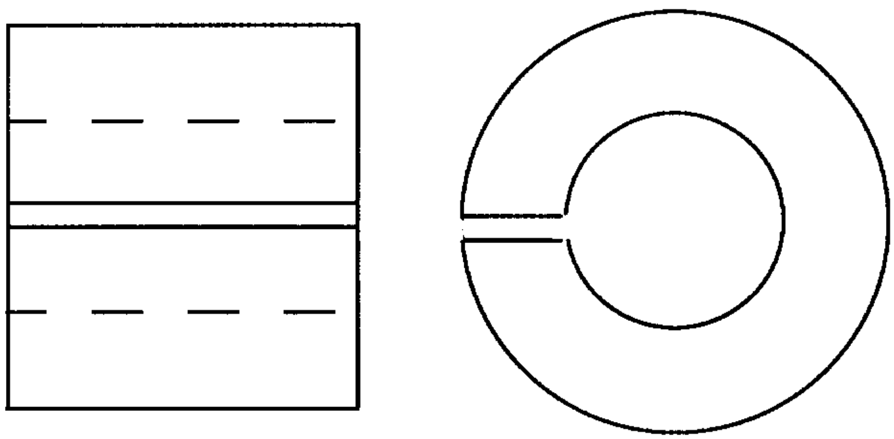
The rate of current rise through the dump SCR should be limited to less than 400 A/μsec for repetative pulses, with 0.5 μsec, 20 V gate drive pulses.

A 1 μH stray inductance in the in the dump SCR discharge circuit at 400 V dump charge would limit the rate of current rise di/dt to:

$$\frac{di}{dt} = \frac{V_{\text{dump cap.}}}{L}$$

$$\frac{di}{dt} = 400\ \text{A}/\mu\text{sec}$$

The dump capacitor discharge circuit has most likely an estimated inductance of 0.5 to 2 μH. It is therefore possible to exceed the SCR di/dt ratings, especially since higher dump voltages can be set. A soaking reactor of several μH should be installed in series with the dump SCR, to limit the rate of current rise to within acceptable limits. The reactor can be made from 4 mil silectron steel cores with a small air gap of about 20 mil. The airgap reduces the remnant field in the core shown in Fig. 9, to about 200 Gauss. This remnant field would be about 12 kG after the first pulse without an air gap. A high remnant field renders the core inductance ineffective for further pulses of the same polarity.



inner diam. - 1.5 inches
outer diam. - 3.5 inches
length - 3.0 inches

gap - 0.02 inches
material - 4 mil silectron steel
Arnold Eng. Type L4

Fig. 9. Soaking Reactor Core

Effective di/dt limiting at dump SCR turn on is obtained by passing the discharge wires from the dump capacitors through the center hole of two cores. The inductance of the cores can be calculated from:

$$L = \frac{N\Phi}{I} \text{ Henry}$$

and is plotted as a function of the current in Fig. 10 for 2 cores in series.

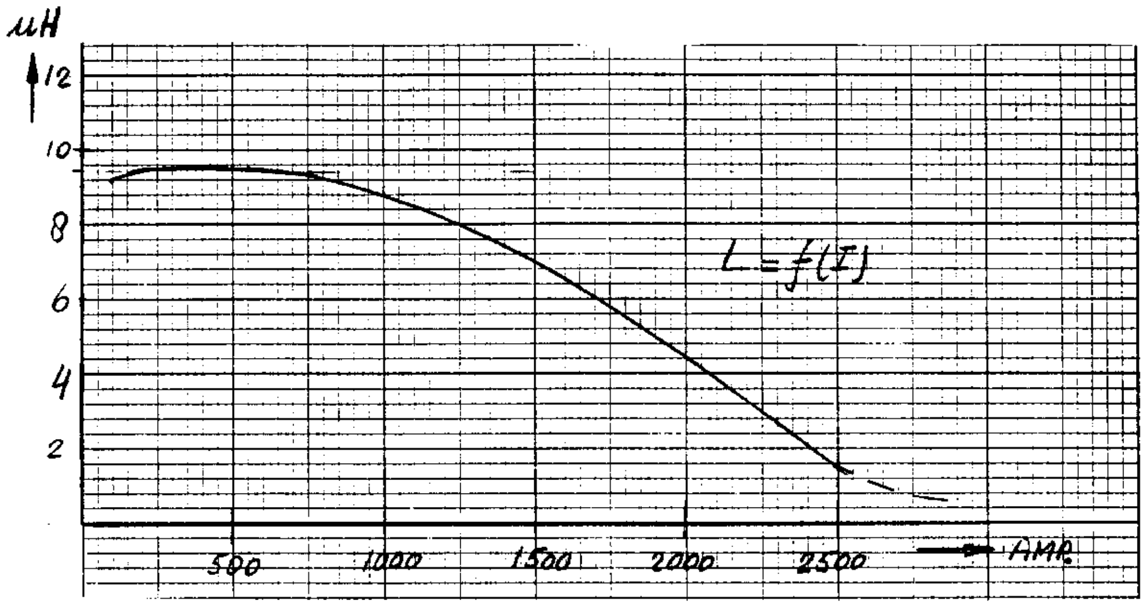


Fig. 10. Soaking reactor inductance for
two cores per figure 9.

A 9.5 μH inductance will limit the initial di/dt to about 40 A/μsec.

An auxiliary turn passed through the cores produces a pulse to latch the run SCR gates negative when a dump occurs, and another turn can be used to supply a convenient trigger pulse for oscilloscopes or other equipment.

3.7 Choosing the Dump Capacitor

When the dump charge stored in the dump capacitors is released, it reverse biases the run SCR's until all the charge has bled off. This charge bleed off time must be longer than the turn off time of the run SCR's. Another way to look at this is to say that the dump capacitors must have enough charge to supply 10,000 Amp for a duration of at least t_q seconds. Removal of the run SCR gate drive and reverse biasing the run SCR's for a period longer than t_q turns them off.

The charge voltage of the dump capacitor is chosen at 400 V, but higher or lower charge voltages can also be used. The 400 V charge allows reasonable component choices and dump discharge di/dt values. The capacitor has to withstand a reverse dump voltage of 1000 V peak, be bi-polar and have a good surge current rating. A charge safety factor yielding a reverse bias time of about 4 times t_q has been chosen for initial design, but this may be very conservative. The listed t_q for the run SCR's is 100 μsec, thus the dump capacitor must be able to supply 10,000 A for 400 x 10^{-6} sec (safety factor of 4) at 400 V initial charge.

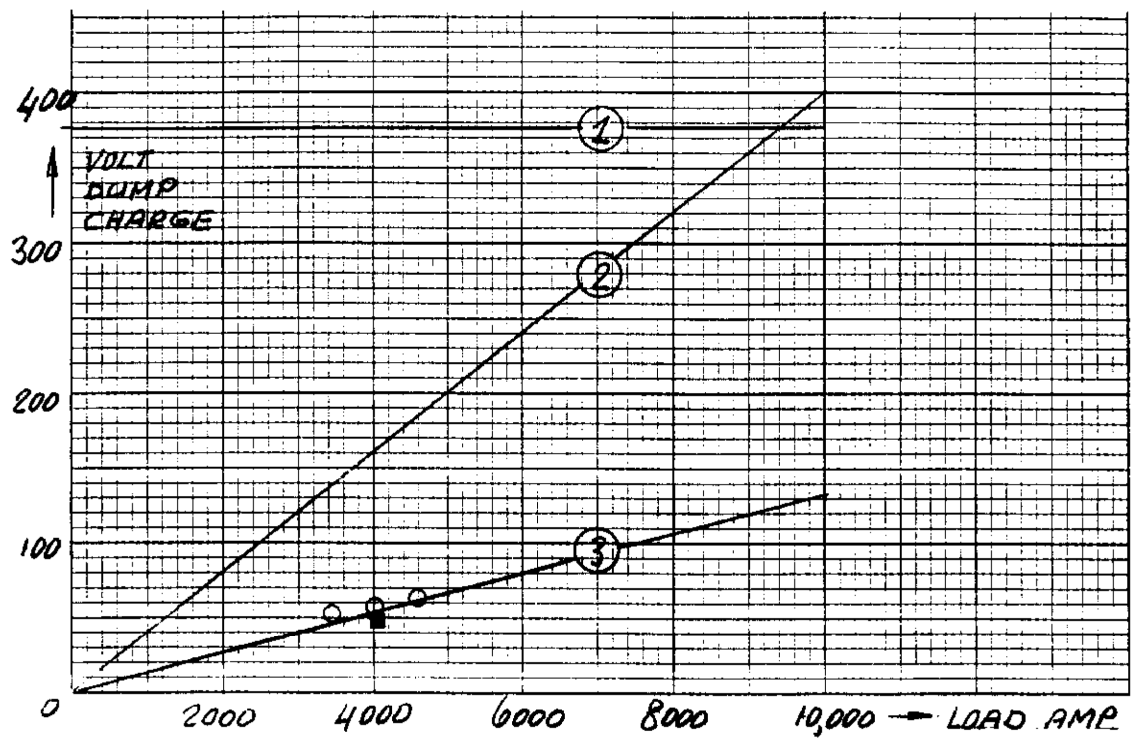
$$Q = CV$$

$$\frac{dQ}{dt} = C\frac{dV}{dt}$$

$$10{,}000 = C\frac{400}{400 \times 10^{-6}}$$

$$C = 10{,}000\ \mu F$$

Choose 4 capapcitors GE #17L611NJ rated 2232 μF, 1000 V peak each. These capacitors have an overpressure interlock and are bi-polar. They are well suited for this dump switch application. A dump charge voltage of 400 V and a low dump charge interlock set at 375 V is used for all load current values. Successful dumps at load currents below 10,000 A can be obtained with less dump charge as shown in Fig. 11. Figure 11 has been adjusted for a 9000 μF dump capacitor and a measured t_q of about 120 μsec. It shows the required charge for a safety factor of 3 and also the minimum required charge.



1. Charge voltage trip level set.
2. Charge voltage needed for t_q safety factor 3.
3. Minimum needed charge voltage for a dump.

■ - tested point yielding a dump failure (see 6.7).
o - tested point yielding a successful dump (see 6.7)

Conditions: dump capacitor 9000 μF
SCR turn off time t_q = 120 μsec.

Fig. 11. Required charge voltage versus load current

4. DESCRIPTION OF THE SWITCH CONTROLS

The attached drawings #ATV061489MTF Sheets 1 through 27 show all switch controls. Sheets 1 and 2 describe the switch quite well. Sheet 1 shows two standard beamline power supplies on the right hand side. Both power supplies have the same input phasing, one is used as a master power supply and the other as a slave. The slave power supply has its current regulator disabled and receives synchronized firing pulses (Sheet 4) from the master power supply for each phase. Current regulation is 0.05%.

The load current passes through the dump switch run SCR's to the load. The power supply current reference control runs via a reference control card (Sheet 15). This card limits the power supply output current in 2000 A steps, regardless of the input reference demand current. These steps are obtained from current sensors (proximity switches) mounted at each run SCR sharing resistor. Higher load currents are automatically permitted as more run SCR's start conducting their share of the load current. This control prevents operation of run SCR's above their 2000 A rating, which could be caused by a gate drive failure. Another reference limit control comes from the dump resistor tap setting (Ref. 1). The dump resistor taps make it possible to select dump resistors from $25 \times 10^{-3}\ \Omega$ to $300 \times 10^{-3}\ \Omega$. A combination of high operating currents and high dump resistor values is destructive, when the dump voltage exceeds 1000 V. Tap sensing at the dump resistor automatically limits the power supply current to:

$$IR_D < 1000 \text{ V}$$

regardless of the demand current.

Running the P.S. reference via the reference control card is a must. An interlock is provided to prevent operation of the P.S. from the built in local current reference.

The output current of each power supply is summed and available for remote readout at a scale factor of 1000 A/V (Sheet 16). Power supply on/off/reset commands come in via the power supplies (required by the MTF). The short reset command pulse needs to be stretched (Sheet 17) to allow enough time for interlock relays to pickup and complete the loop before the reset pulse stops.

The center of Sheet 1 shows the interlocks which come in at 12 channel interlock summation cards shown in Sheets 13 and 14. The interlock summation trips the power supplies and fires the dump switch. Local and remote status shows which interlocks tripped, but there will always be several interlocks, e.g. "low capacitor dump charge", "dump resistor current high", etc. that will register a trip when the dump fires.

The left hand side of Sheet 1 shows what happens when the 8 channel dump command distribution card (Sheet 11) receives a dump command. The dump distribution card fires the dump SCR via a fiber optic cable (Sheet 5), it latches on to the first channel where the dump command came in, it activates the dump failure detector (sheet 12), it inhibits dump capacitor charging and it unclamps the negative gate bias at the run SCR's during the period between 30 and 70 seconds after a dump. The negative gate bias at the run SCR's (sheet 5) is initiated by the dump capacitor discharge itself, and can only be reset by removing the a.c. for the gate drive circuits for a period of about 40 second duration. The negative gate bias makes it very hard for noise to retrigger the run SCR's while they block the forward dump voltage across the dump resistor.

The dump failure detector (Sheet 12) is enabled at 8×10^{-3} sec. after a dump for a duration of 30 seconds. A dump failure occurs when one or several run SCR's conduct current during a period immediately following a dump command. Proximity switches CS1B through CS6B mounted close to the sharing resistors sense the presence of current, which makes them switch on. This activates and latches an optically coupled SCR and interlock relay (Sheet 12). The cause of a dump failure should be investigated and a dump failure should not be reset remotely. The dump failure detector provides a trigger pulse for external use and registers which SCR(s) failed. Low current dump failures of less then about 150 A/SCR will not register. High current dump failures through one SCR will destroy it. Firing a backup switch could save the SCR but there is most likely something wrong anyway. The run SCR's must be checked after dump failures at high currents.

The dump pulse distribution card and first fault latch (Sheet 11) respond only to the first dump command that occurs.. Subsequent dump commands do not come through. The system is built for high isolation and high noise immunity at the input and output side. The dump SCR receives its trigger via a fiber optic link. Reset of the dump distribution card occurs along with resets to the other circuits. A permanent reset command, as a result of a relay failure, will still allow a dump pulse to come through and complete a successful dump.

The charging power supply is shown on Sheet 6. The dump capacitor stores a lethal amount of energy. This charge is automatically removed via K3 when the doors are opened or the a.c. is interrupted. A grounding stick is supplied to short the capacitor bank and must be applied, in addition to "lock out and tag out" procedures when the system is being worked on.

Pressure switches at the capacitors indicate capacitors failures. Charge regulation (Sheet 6) takes place at the primary side of the charging transformer via a soft start solid state relay. This avoids high inrush currents, which can be a nuisance by causing circuit breaker trips. The charge regulator regulates better than 1% above 50 V and allows setting of various charge and low charge interlock levels. Normally used levels are 400 V charge and 375 V trip.

A water leak detector (Sheet 7) mounted in the dump switch cabinet trips an interlock and can ring a bell when water is present.

The rest of the sheets show interconnection and wiring information. Sheet 18 shows a proposed magnet quench detector. It has not been further developed because the MTF supplies their own quench and lead voltage detectors. A good understanding of the dump switch can be obtained by studying the drawings.

5. MECHANICAL CONSTRUCTION

All switch components (Sheet 2) are mounted in a 72"H x 36"W x 30"D steel cabinet and require front access only. The controls are in a relay rack that can be mounted remotely. Power and cooling water are supplied via 2 copper power buses of 1" x 6" x 59" long. Each copper bus has a 7/16" diameter cooling water hole drilled through its entire length. All cooling water is supplied via the power buses and runs serially through all components (Sheet 2). This method saves cooling water, but requires that the cooling water inlet is at the positive bus, so that it reaches the diodes and SCR's first. The estimated flow is about 4.2 gallons per minute at 100 PSI differential pressure. The switch can withstand 300 PSI test pressure. Temperature rises can be calculated from:

$$\Delta T(^{o}C) = \frac{3.8 \times KW}{GPM}$$

The SCR heatsinks and sharing resistors are directly bolted to predrilled holes in the power buses. The power buses are mounted vertically with insulators to a back plate and protrude through the top of the cabinet. The dump capacitors are mounted at the bottom.

6. DUMP SWITCH TESTS

Several tests were performed at the dump switch prior to final installation. These tests and their results are briefly described hereafter for future reference.

6.1 Hydrostatic Tests

Cooling water flow at ΔP = 100 PSI is 4.2 GPM
Pressure test at 300 PSI -OK.

6.2 High Potential Tests Without Water and External Electrical Connection

SCR's and buswork to ground at 2500 Vdc, 1 min	125 MΩ
Capacitor charging power supply to ground at 2500 Vdc, 1 min.	infinity

Dump capacitor bank to ground at 2500 Vdc, 1 min	0.5 MΩ
Total system without dump capacitor bank to ground at 250 Vdc, 1 min	125 MΩ

6.3 Run SCR Gate Current and Minimum SCR Anode to Cathode Voltage $V_{AK\text{-}min}$ Needed for SCR to Latch On

SCR	Measured dc gate current and voltage at $V_{AK} = 0$	Minimum SCR turn on V_{AK} min *
S1	2.1 A / ~ 3 V	1.57 V
S2	2.1 A / ~ 2.9 V	2.24 V
S3	1.73 A / ~3.7 V	1.83 V
S4	1.42 A / ~3.8 V	2.01 V
S5	1.65 A / ~ 3.6 V	1.66 V
S6	1.73 A / ~ 4 V	1.61 V

* The switch design allows a V_{AK} min of 3.6 Volt. V_{AK} min is fairly constant at gate currents above 1 A but increases about 0.5 V to 1 V at 0.5 A gate current. A dc gate current of 1.5 to 2.5 A is a good choice.

6.4 Run SCR Forward Drop and Load Current Sharing Test

Connect a 5000 Adc/50 Vdc (Transrex) power supply via the 10,000 A dump switch to a B2 magnet (7.16×10^{-3} Ω at 6.1×10^{-3} H). Install a temporary 260×10^{-3} Ω dump resistor.

SCR turn on test:

Set 1000 Adc - S1,S2,S3,S5,S6 - On
S4 - Off
Set 1400 Adc - All SCR's - On

Check SCR forward voltage drop. Run one SCR at a time.

SCR	Forward voltage drop volts at	
No.	100 A	2000 A
S1	1.59	1.68
S2	1.56	1.62
S3	1.39	1.62
S4	1.55	1.62
S5	1.32	1.5
S6	1.29	1.48

The SCR forward drop at 2000 A is around 1.6 V. This is in agreement with the data sheet values of 1.9 V at 25°C, however the SCR operating temperature is also higher than 25°C. The published forward drop is about 1.6 V at 2000 A, and 125°C. The SCR clamping pressure is correct. Low clamping pressure results in excessive forward drop, which is not the case.

6.5 Run SCR Heatsink Temperature Test

Set 4000 Adc and run only SCR's S3 and S4 and measure the heatsink temperature on the outside.

Inlet water temperature		29°C
Center Sink	S3, S4	43°C
Outer Sink	S3	42°C
Outer Sink	S4	37°C

6.6 SCR Sharing Resistor Tests

Run one SCR and measure the sharing resistor surface temperature at the center of the off the stainless steel resistor tube.

Water inlet temperature - 26°C

Resistor No.	Resistor Center Operating Temp °C at 1700 *	1800 A	2000A
R1	86	92	105
R2	84	90	102
R3	86	92	110
R4	82	88	100
R5	80	86	99
R6	78	84	96

*Estimated from 1800 A and 2000 A column.

R_4 voltage drop is 2.63V at 2000A which yields $R_4 = 1.3 \times 10^{-3}\ \Omega$. The normal maximum SCR operating current is 1700 A. The maximum resistor temperature at 10,000 A with 6 SCR's on and 40°C water inlet temperature at the switch is:

86 + 14 + 10 + 28°C = 138°C.

in which:

86°C is the resistor temp. with 26°C water inlet
14°C is the addition for 40°C water inlet.
10°C is the addition for water heating from SCR's.
28°C is the addition for water heating at the last resistor caused by other series resistors.

The overtemperature trip is set at 120°C. This trip may need to be increased to 140°C for 10,000 A operation and 40°C water inlet. Another solution is to split the cooling into two parallel circuits.

Comment

Future resistors could be made smaller ($0.5 \times 10^{-3}\ \Omega$) by choosing a larger O.D. or shorter stainless steel tube, because SCR turn on is good. This would reduce the losses and the operating temperature of the resistor.

6.7 Dump Test

Check for the minimum dump charge voltage needed for a successful dump (run SCR shut off).

Load Current	Dump Capacitor Charge Volt	Run SCR Shut off Completed
2000	50	Yes
2500	50	Yes
3000	50	Yes
3500	50	Yes
4000	50	No
4000	60	Yes
4500	65	Yes
4500	60	Yes

This interesting test could be carried out to 10,000 A, but it could ruin a run SCR and it is therefore not recommended. From these tests we may estimate that a successful dump at 4500 A requires about 60 V dump charge in 9000 µF.

This 60 V dump capacitor charge has to supply 4500 A for the duration of the turn-off time t_q of the dump switch. t_q can be estimated from this as follows:

$$Q = CV$$

$$\frac{dQ}{dt} = C\frac{dV}{dt} \quad \text{or:} \quad i = C\frac{\text{charge voltage}}{t_q}$$

thus:

$$t_q = \frac{9000 \times 10^{-6} \times 60}{4500}$$

$$t_q = 120 \times 10^{-6} \text{ sec}$$

The run SCR test data sheets lists a t_q = 100 µsec at 2000 A, 125°C.

The estimated minimum charge voltage V required for a successful 10,000 A dump would be:

$$120 \times 10^{-6} = \frac{9000 \times 10^{-6}\,V}{10000}$$

$$V = 133 \text{ Volt}$$

An operating dump capacitor charge voltage of 400 V yields a maximum allowed turn off time t_q at 400V of:

$$t_q = \frac{9000 \times 10^{-6} \times 400}{10000}$$

$$t_q = 360 \times 10^{-6} \text{ sec maximum at 400V in 9000 } \mu\text{F.}$$

There is about a turn-off time safety factor of 3 with a 400 V dump capacitor charge in a 9000 μF dump capacitor at 10,000A load current.

6.8 Dump Failure Sensing Circuit Test

A dump failure occurs when the run SCR's carry current shortly after a dump command. Current sensors CS1B through CS6B sense the presence of run SCR current. These current sensors have to switch off immediately after run SCR conduction stops. Tests were made to measure the elapsed time, after a dump command, needed by the current sensors to switch off. The dump failure detector is enabled at 8×10^{-3} sec (chosen value) and "switch off times" t_{off} larger than 8×10^{-3} sec give therefore a dump failure indication.

Initial tests for t_{off}.

Below 2000 A all sensors switch off, and stay off in about t_{off} = 100 μsec. Above 2000 A some sensors switched back on after being off for about 150 μsec. It was concluded that the current sensors were reactivated by stray fields from the dump current flowing in the main power buses. A temporary magnetic shield was installed to eliminate this stray field effect.

Tests for t_{off} with temporary shield at CS1A, CS1B:

S1, S2	2000 A	$t_{off} \sim 400 \times 10^{-6}$ sec
S1,S2	4000 A	$t_{off} \sim 400 \times 10^{-6}$ sec*
S1,S2,S4	4800 A	$t_{off} \sim 400 \times 10^{-6}$ sec*
S1,S5,S6	4800 A	$t_{off} \sim 150 \times 10^{-6}$ sec

*some bounce at end.

Current sensor sensitivity with temporary shield at CS1A, CS1B:

CS1A pickup at ~215 A
CS1B pickup at ~115 A

False pickup tests with temporary shield in stalled at CS1A, CS1B and run SCR's S4, S5, S6 dumping from 4800 A- no stray field pickup.

CONCLUSION

The temporary magnetic shield cures the stray field pickup problem up to 5000 A (test stand limit). Install 6 final shields and perform final false pickup tests above 5000A at the MTF at a later date.

The pickup sensitivity of the current sensors after installation of the final shield was tested and the results are shown below:

	Pickup Amp	Dropout Amp
CS1A	116	92
CS1B	82	77
CS2A	138	105
CS2B	133	107
CS3A	108	83
CS3B	114	92
CS4A	135	109
CS4B	150	105
CS5A	112	81
CS5B	135	94
CS6A	174	91
CS6B	142	104

7. ACKNOWLEDGEMENT

The Mechanical Group helped with the mounting of the power buses and cooling connections. Walt Jaskierny designed the reference limit control, power supply firing repeaters, made printed circuit cards, assembled and tested all components and suggested many design improvements. He contributed substantially to the successful completion of the 10,000 A dump switch and it's controls.

8. REFERENCE

Ref. 1, TM #1161 Cat. #2080.000, A.T. Visser March '90 Design Note of a 10,000A, 2 M Joules Dump Resistor for the Magnet Test Facility.

FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED-PSI	MTF		

SUBJECT: SSC MAGNET TEST FAC
VARIOUS POSSIBLE Q.S. SCHEMES, EL

NAME: A VISSER

DATE: 5/24/88

REVISION DATE:

#ATV05 2488

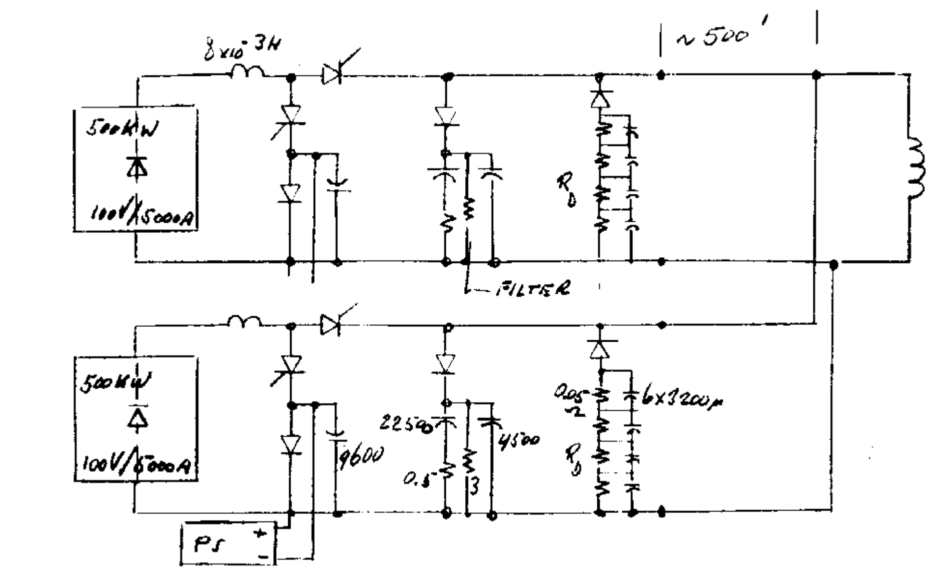


FIG. 1 EXCISTING D.S.

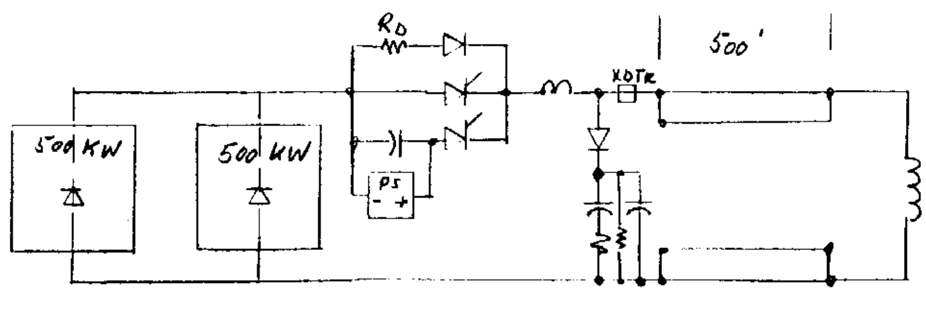


FIG 2 D.S.

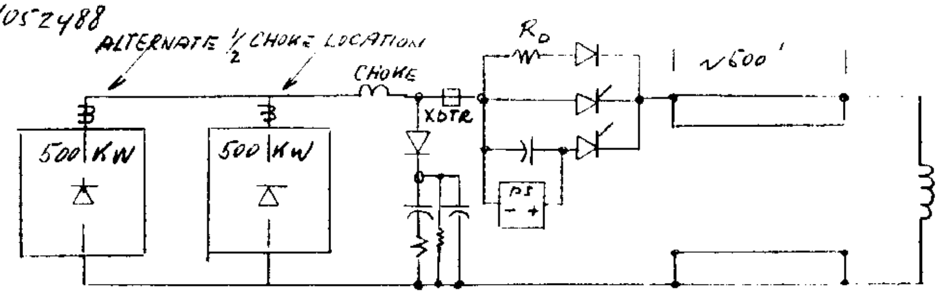


FIG 3 D.S.

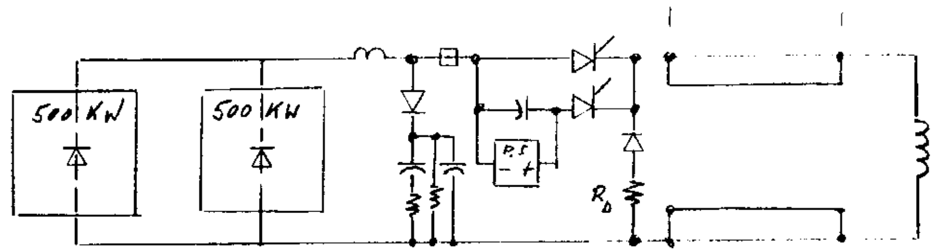


FIG. 4 S. WATCH OUT FOR CHOKE $\frac{1}{2}LI^2$!

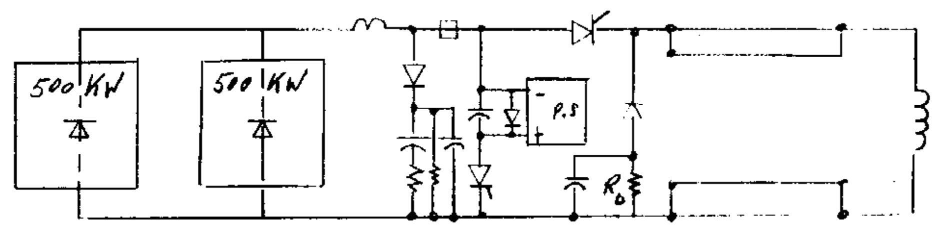


FIG 5 D.S.

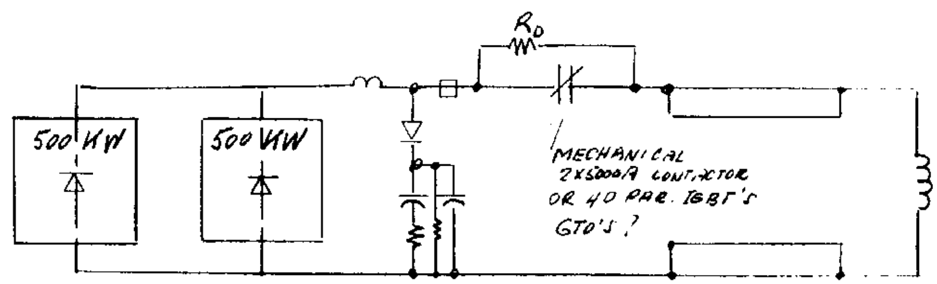
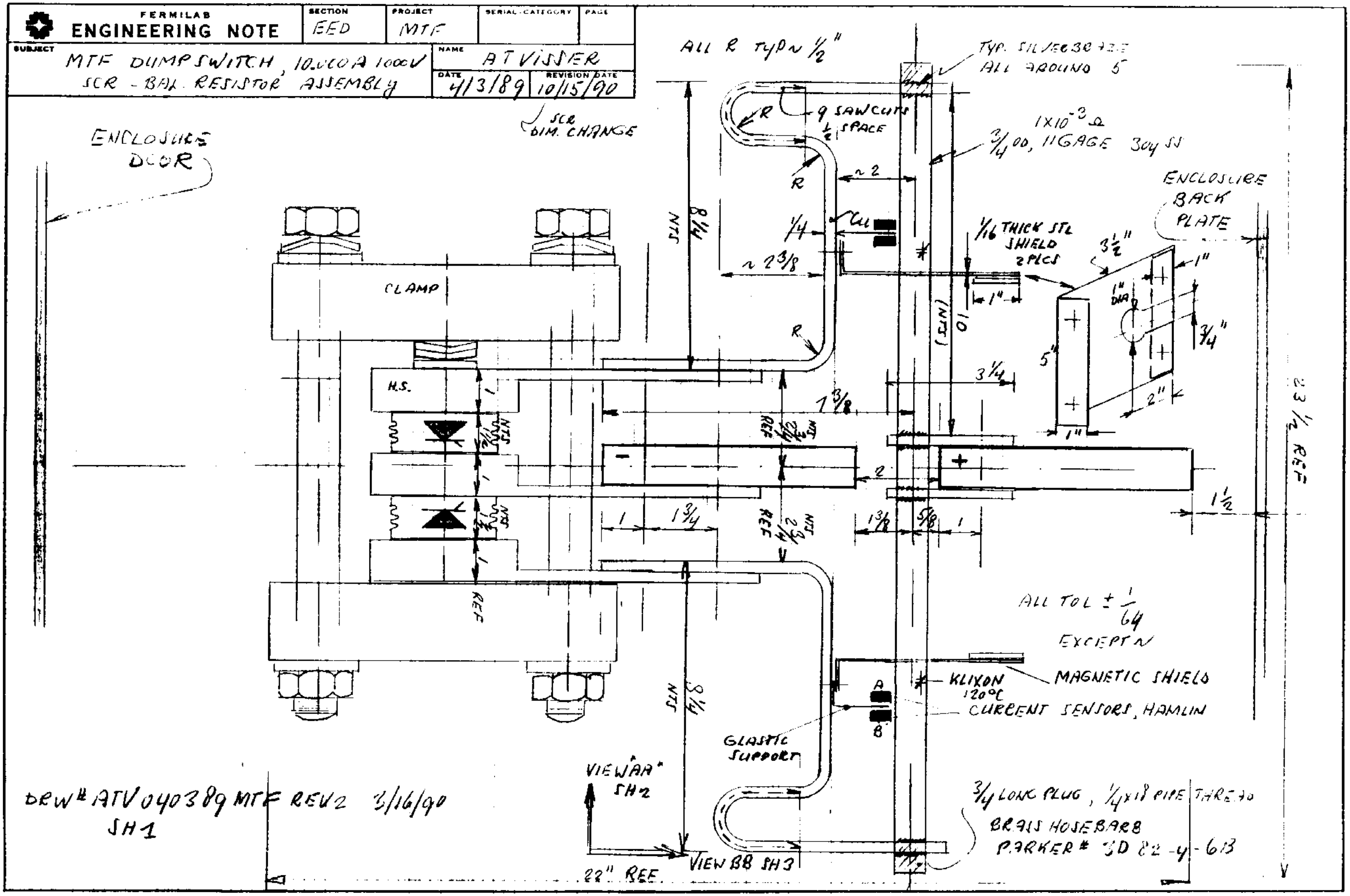


FIG 6 D.S. OPENING DELAY ~100×10^{-3} SEC MECH.

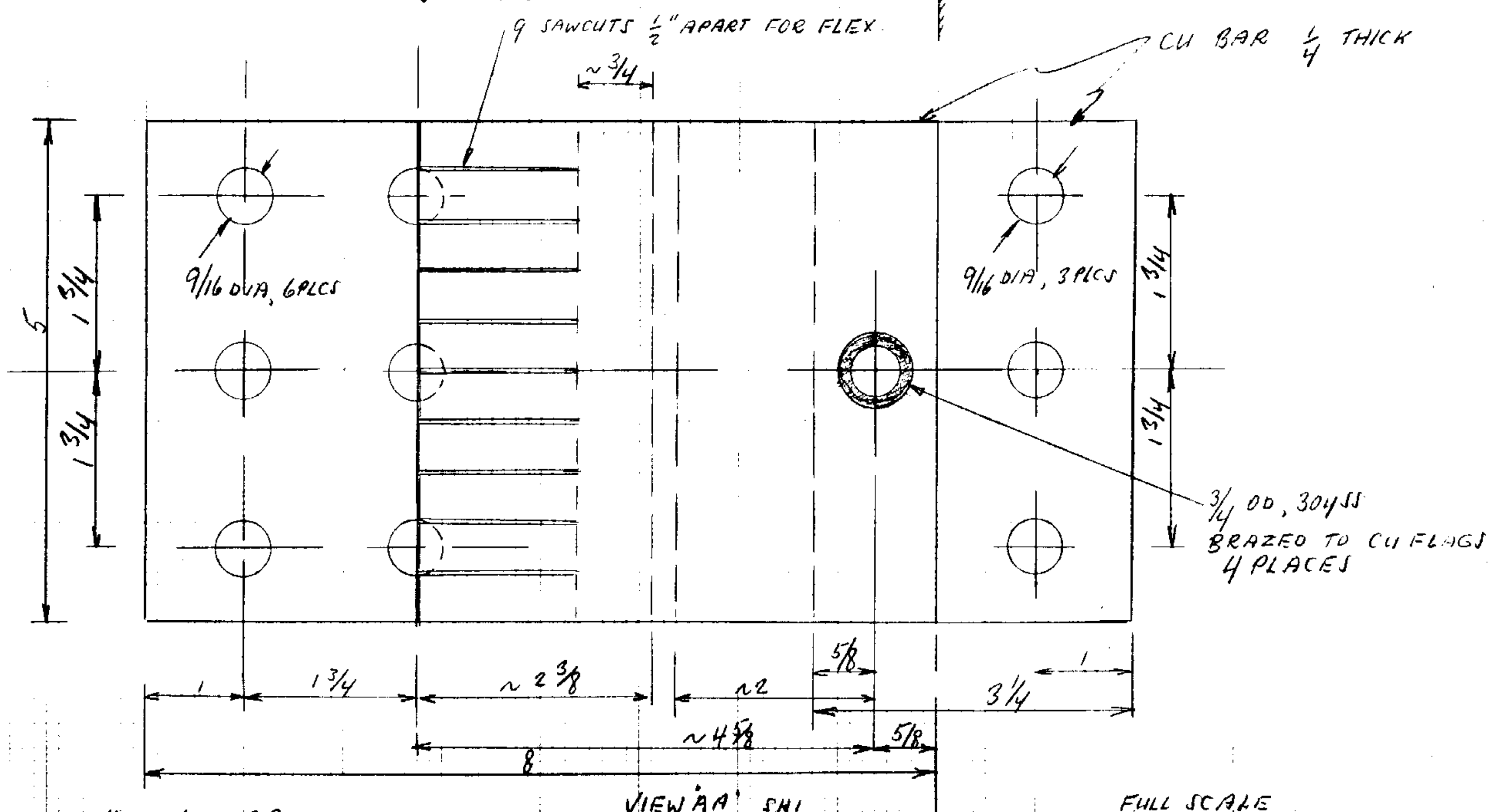

FERMILAB ENGINEERING NOTE
SECTION EED
PROJECT MTF
SERIAL-CATEGORY
PAGE
SUBJECT MTF DUMPSWITCH, 10,000A 1000V SCR - BAL. RESISTOR ASSEMBLY
NAME AT VISSER
DATE 4/3/89
REVISION DATE 10/15/90
SCR DIM. CHANGE
ENCLOSURE DOOR
ALL R TYP ~ 1/2"
TYP. SILVER SOLDER ALL AROUND 5
9 SAWCUTS 1/2 SPACE
1X10^-3 Ω
3/4 OD, 11GAGE 304 SS
ENCLOSURE BACK PLATE
1/16 THICK STL SHIELD 2 PCS
CLAMP
H.S.
NTS
REF
ALL TOL ± 1/64 EXCEPT ~
KLIXON 120°C
MAGNETIC SHIELD
CURRENT SENSORS, HAMLIN
GLASTIC SUPPORT
VIEW "AA" SH2
VIEW BB SH3
22" REF.
23 1/2 REF
3/4 LONG PLUG, 1/4 x 18 PIPE THREAD
BRASS HOSEBARB
PARKER # 3D 82-4-6B
DRW# ATV040389 MTF REV2 3/16/90
SH1

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED	MTF		

SUBJECT: MTF DUMPSWITCH, 10 000A SHARING RESISTOR ASSEMBLY

NAME: A.T. VISSER
DATE: 040489
REVISION DATE:

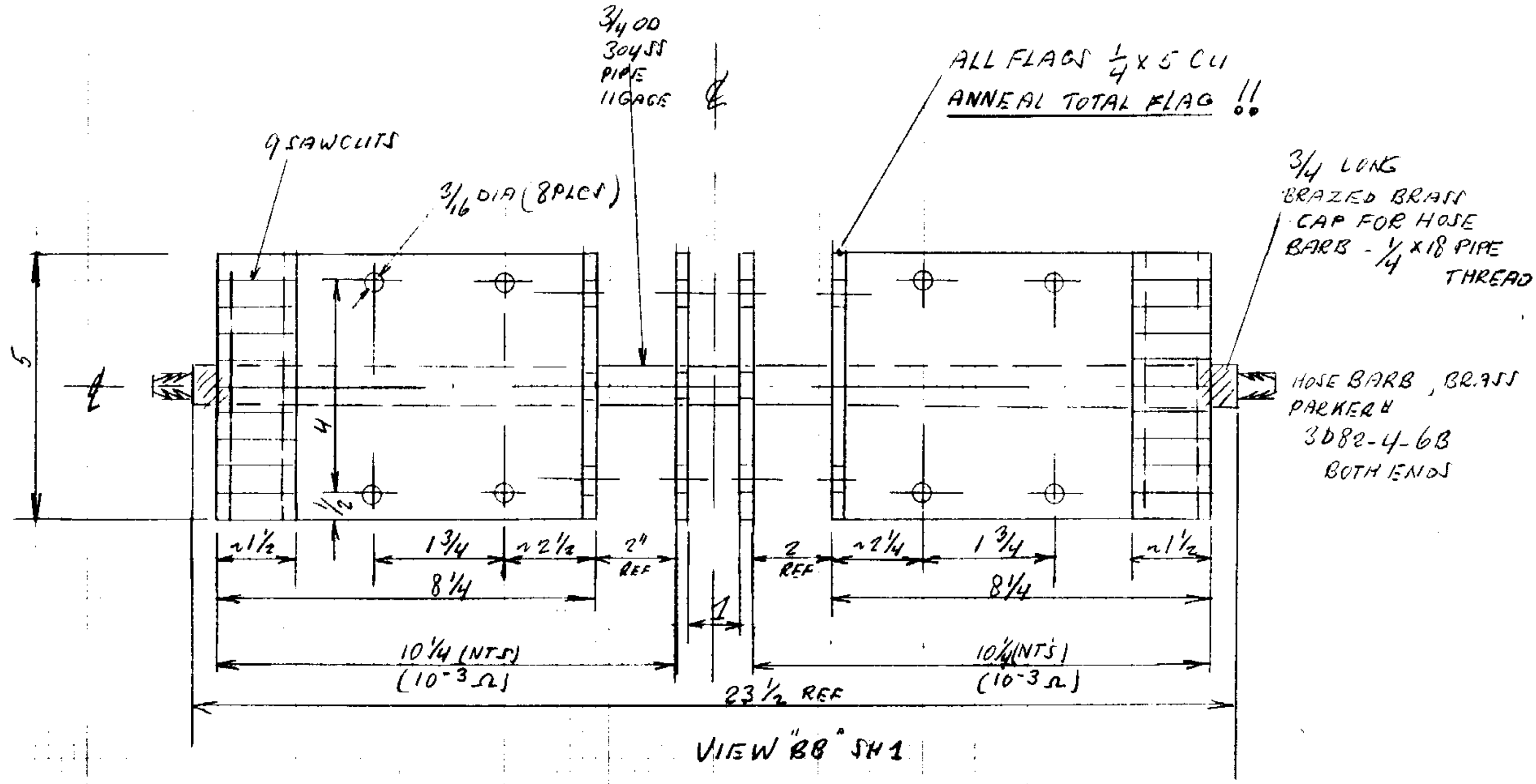


DRW# AFV040389MTF REV0
SH2

FULL SCALE
MAKE 3 PCS

FERMILAB ENGINEERING NOTE	SECTION EED	PROJECT MTF	SERIAL-CATEGORY	PAGE
SUBJECT MTF DUMPSWITCH, 10000A, 1000V SHARING RESISTOR ASSEMBLY		NAME A T VISSER		
		DATE 04/04/89	REVISION DATE 3/15/90	

~(SCR) DIM. CHANGE



DRW# ATV040889MTF REV3 3/16/90
SH3

ALL TOL ± 1/64 EXCEPT ~

FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED-BS	MTF	G. Tool	

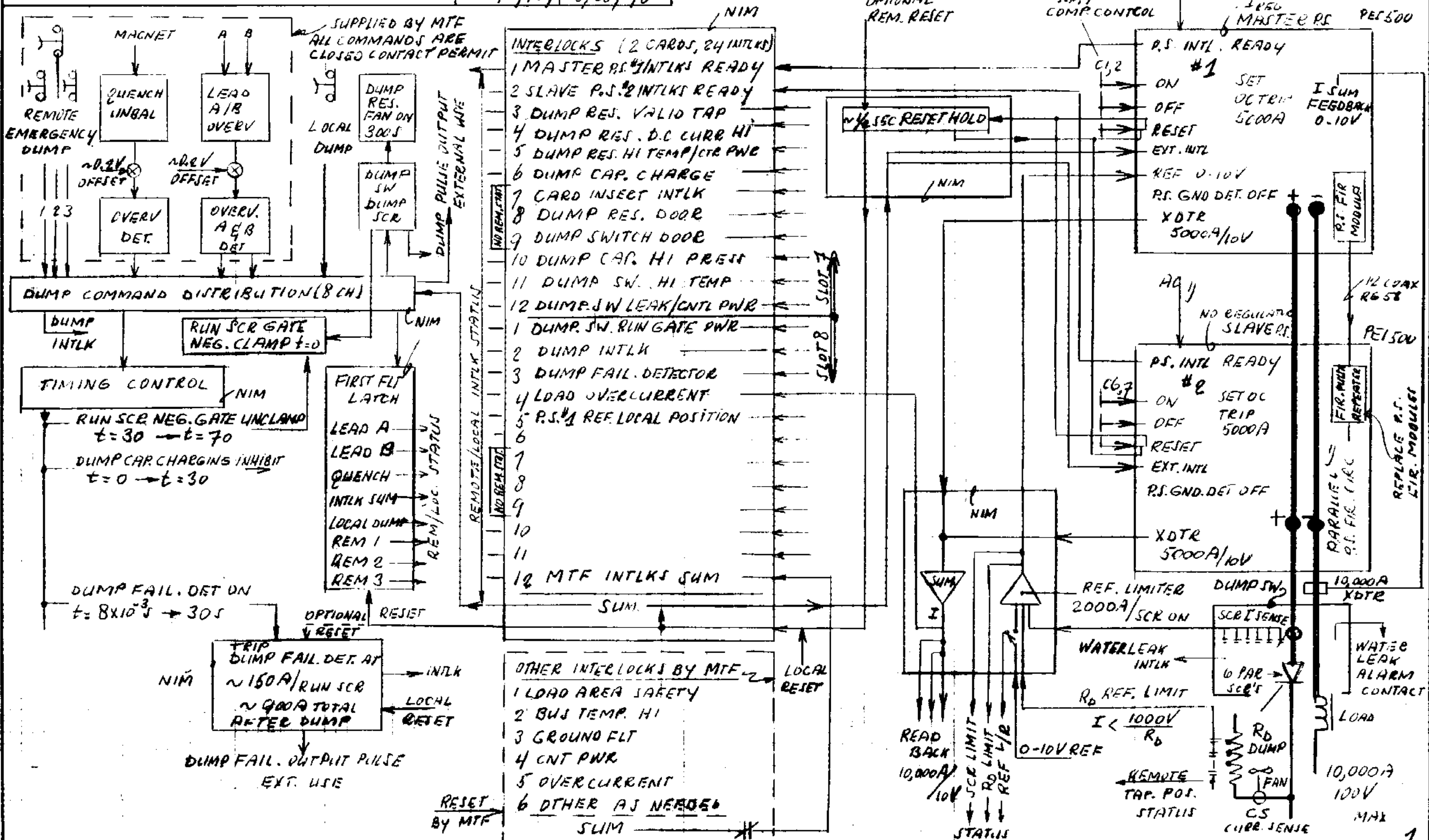
SUBJECT: MTF DUMPSWITCH, 10.000 A/1000V CONTROL AND INTERLOCK FLOW.

NAME: AT VISSER

DATE: 6/14/89 REVISION DATE: 8/28/90

12/90

DRW# ATV 061489 MTF



26

12/90

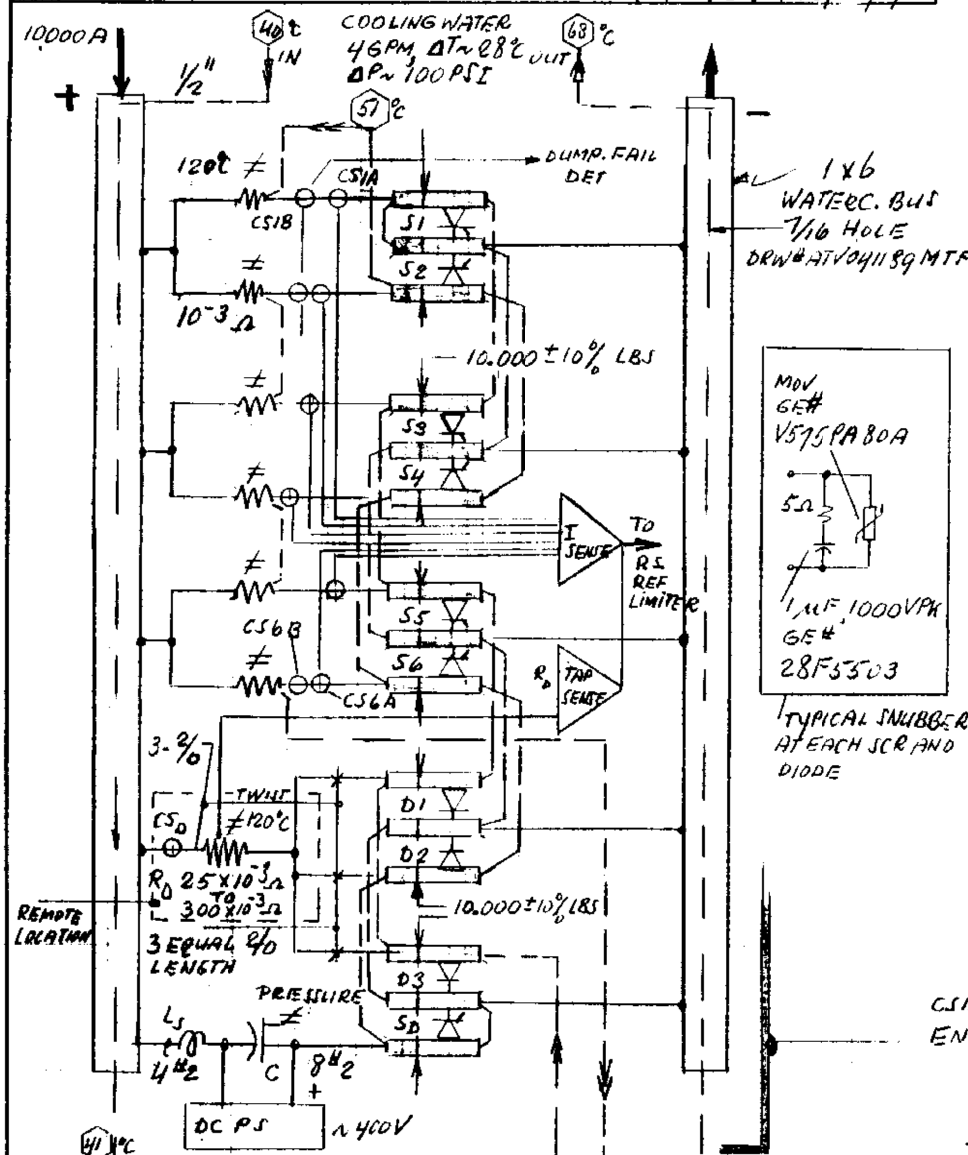
FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED BS	MTF/SSC		

SUBJECT: MTF DUMPSWITCH SUMMARY 10.000 A, 1000V

NAME: A.T. VISSER

DATE: 1/31/89 REVISION DATE: 28/8/90



\# ATV061489MTF

NOTE: CURRENT PER RUN SCR 1670A AT 10000ADC NORMAL
ALLOW PER RUN SCR 2000 A " " MAX UNBAL.
ALLOW 10.000A WITH 5 SCR'S ON

COOLING ΔP - 100PSI, 4 GPM
MAX T_{IN} - 40°C
MAX T_{OUT} - 70°C

LOSSES 6 SCR'S ON - 35KW AT 10.000 AMP

V_{DROP} - 3.5 VOLT

CLAMPING PRESSURE IN LBS
FOR 10000 LBS FINGER TIGHTEN NUT AND ADD 1½ TURNS
CHECK SCR FORWARD DROP < 1.6 V AT 2000A/SCR AT PROPER PRESSURE & 125°C
WATERCOOLED HEATSINK - AAVID ENG. INC. # A-004-349-72 FERMI # 6004-EC-76805
CLAMP - VEP # VE 9560-3120, 6" BOLT CENTER (ALT. PSI # 9020-X-10)

≠ 120°C KLIXON TI # 4700 K01-33

$10^{-3}\,\Omega$ WATERCOOLED BALANCING RESISTOR, DRW# ATV040389MTF 10" 304 SS PIPE, 3/4" - 11 GAGE, 0.8074 LBS/FT

L_S CUT CORE SOAKING REACTOR, 10x10^-6 H, DRW# ATV051289MTF

C CAPACITOR, 4 x GE # 17L611NJ, 2232 μF, 1000VPK EACH

S1 - S6 IR # 88-6563-1800V, 2350 ARMS, t_q = 100 μs, 125°C, INVERTER SCR (ALT GE # C770PNJ)*

S_D IR # S77R18A, 1800V, 3060.9 AV, $\frac{di}{dt}$ > 300A/μs, 125°C, RECTIFIER SCR (ALT. GE # G781PN)

D1 - D3 MARCONI # DS 2103 SW20, 2000V, 5700A AV., 160°C DIODE (ALT WESTCODE # SW20CXC15C, 2000V, 3750A)

R_D TM # 1611, ATV 3/90, $25\times10^{-3}\,\Omega$ TO $300\times10^{-3}\,\Omega$, 2MJ, ΔT~50°C

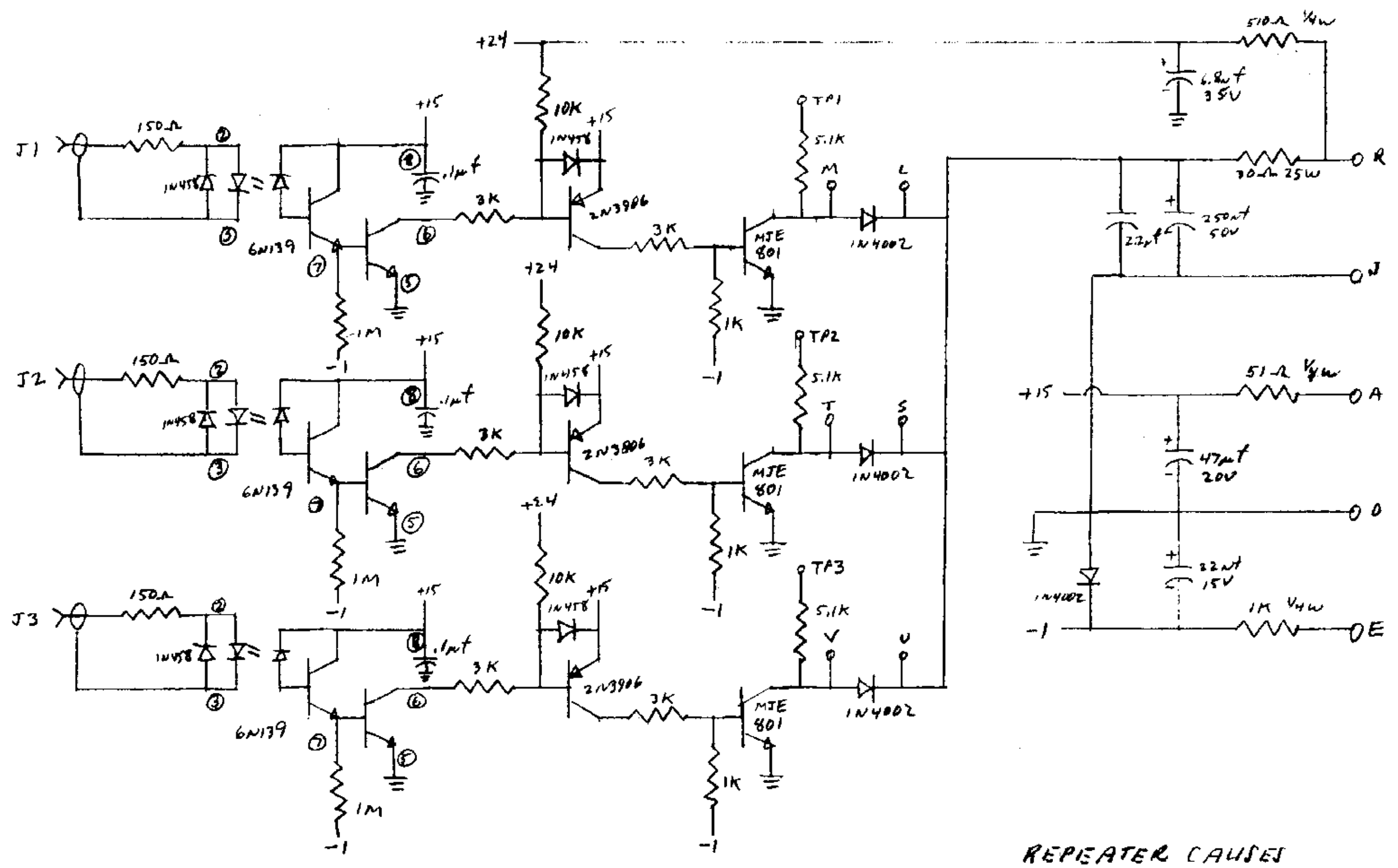
CS1A - CS6B CURRENT SENSOR, HAMLIN # 59145-020

ENCLOSURE 72"H x 36"W x 30"D, NEMA 12, HOFFMAN 723630, FLOOR MOUNT DRW# ATV041489MTF

*OLD # GE # C782PNV701

NATIONAL ACCELERATOR LABORATORY ENGINEERING NOTE	SECTION AD/EES	PROJECT MTF 101A F.S.	SERIAL-CATEGORY	PAGE 1 of 1
SUBJECT MTF DUMPSWITCH 10,000A / 1000 V SLAVE P.S. FIRING PULSE REPEATER		NAME W. JASKIERNY		
		DATE 10 JUL 89	REVISION DATE 8/28/90	

ATV 061489 MTF



REPEATER CAUSES
5μSEC (~0.1 EL. DEGREE)
TURN ON & TURN OFF
DELAY

4

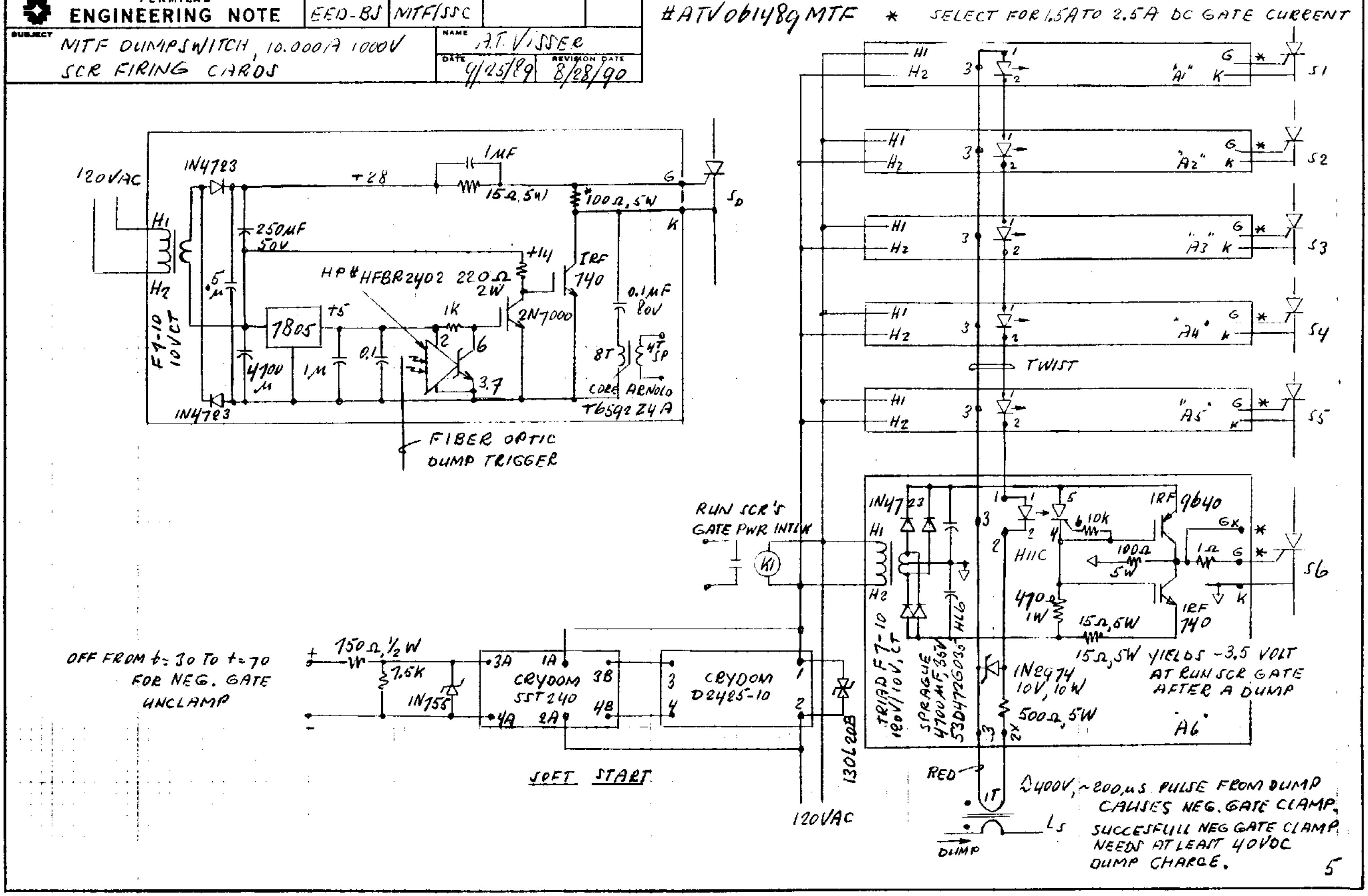
FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED-BJ	NTF/SSC		

SUBJECT: NTF DUMPSWITCH, 10.000A 1000V SCR FIRING CARDS

NAME: A.T. VISSER

DATE: 9/25/89 REVISION DATE: 8/28/90



5

FERMILAB ENGINEERING NOTE

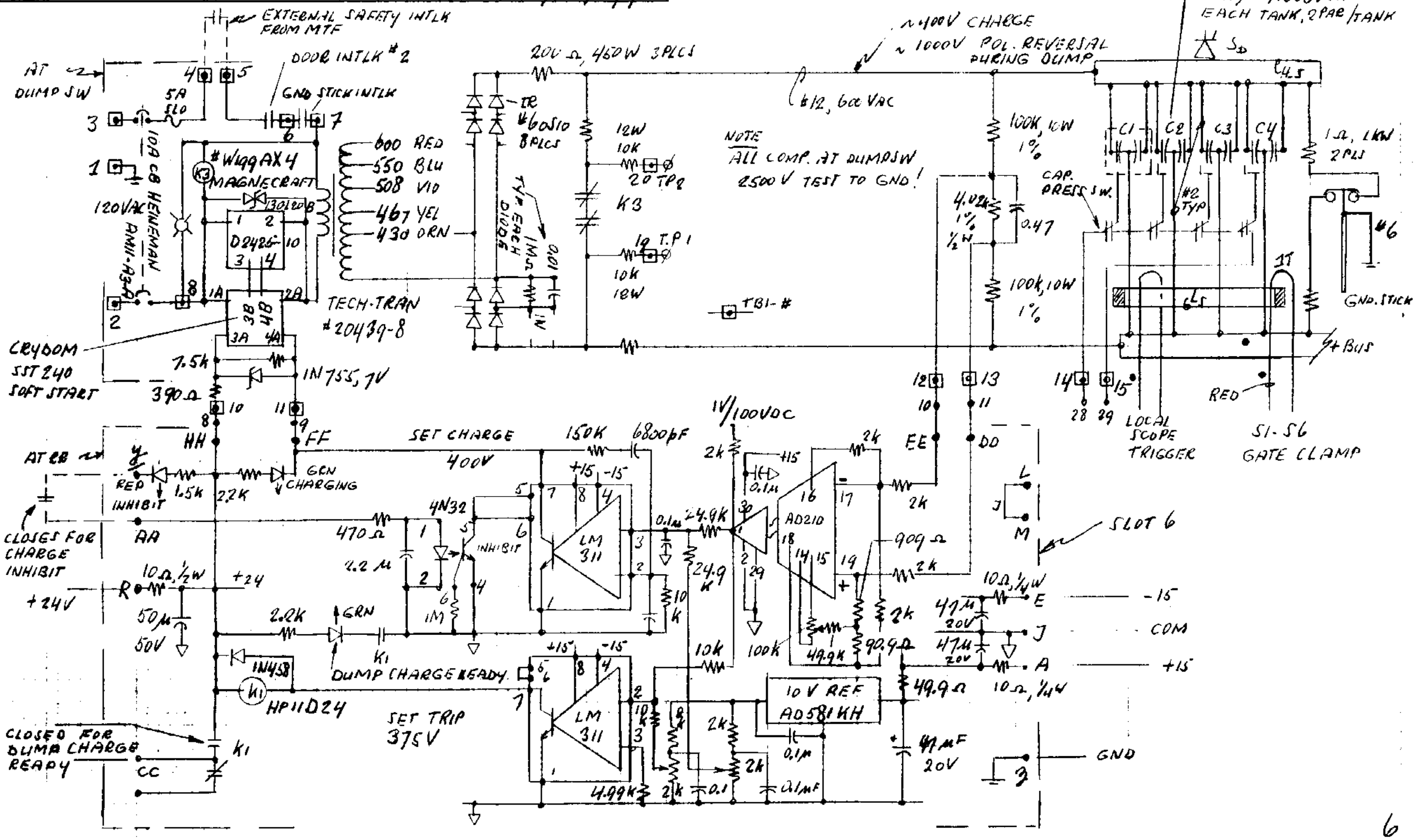
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED-BS	MTF/SSC		

SUBJECT: MTF DUMPSWITCH 10000A, 1000V CHARGE P.S. AND CONTROL

NAME: A.T. VISSER

DATE: 10/2/89 REVISION DATE: 8/28/90 WFJ

ATV061489MTF



FERMILAB ENGINEERING NOTE

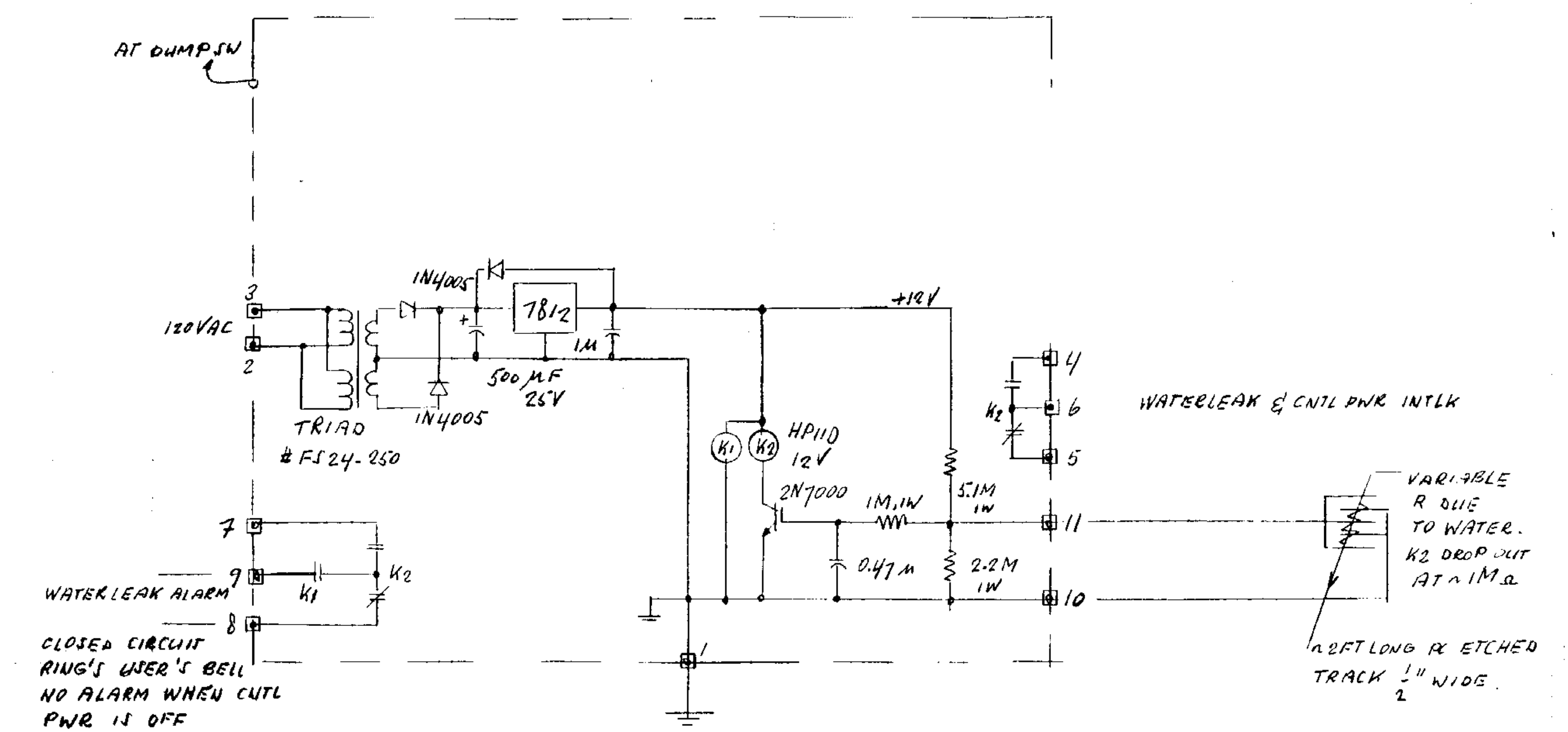
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED-BS	MTF/SSC		

SUBJECT: MTF DUMPSWITCH 10,000A, 1000V WATERLEAK DETECTOR

NAME: A. VISSER/W. JASKIERNY

DATE: 10/17/89 REVISION DATE: 8/28/90

ATV061489 MTF



7

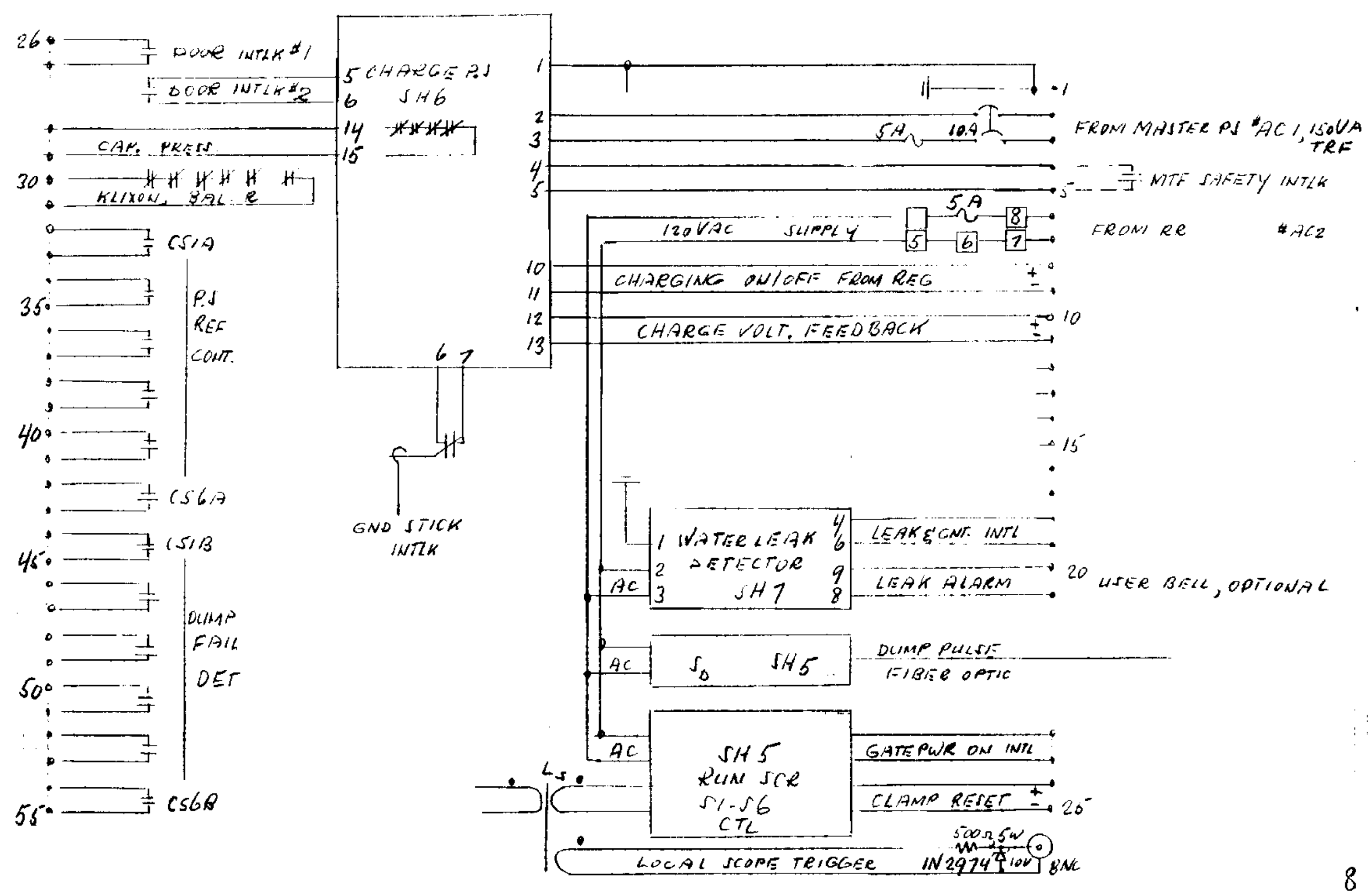
FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	EED/BS	MTF/SSC		

SUBJECT: MTF DUMPSWITCH, 10000 A, 1000 V SWITCH ENCLOSURE INTERNAL CTL WIRING

NAME: A.T. VISSER

DATE: 10/4/89 REVISION DATE: 8/28/90

ATV0614 89 MTF



8

FERMILAB ENGINEERING NOTE

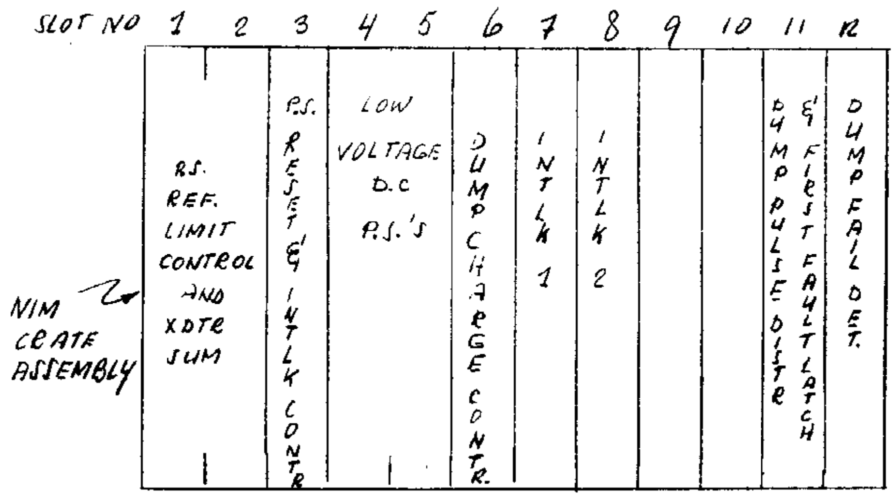
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED BS	MTF/SSC		

SUBJECT: MTF DUMPSWITCH 10,000A, 1000V NIM CRATE ASSEMBLY DETAILS

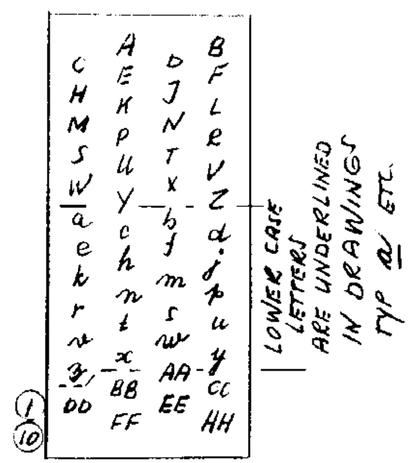
NAME: J.T. VISSER

DATE: 10/31/89 REVISION DATE: 8/28/90

ATV061489MTF

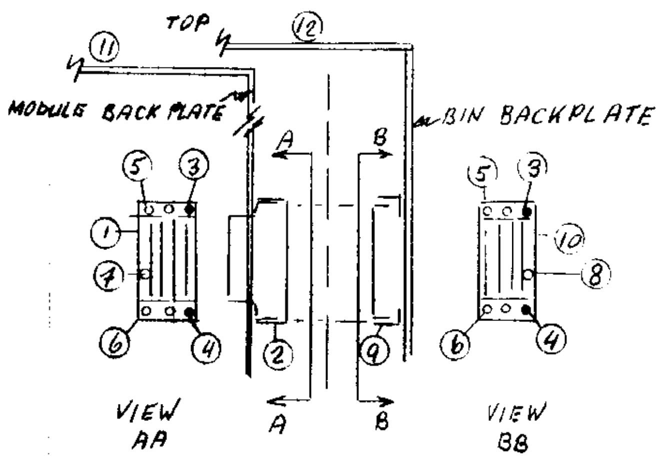


FRONT VIEW



CONNECTOR BLOCK NUMBERS VIEW BB

ITEM	DESCRIPTION	AMP PART NO	NAL STOCK NO
1	CONNECTOR BLOCK, MODULE	201358 - 3	1431 - 1001
2	PIN HOOD INTERNAL	202394 - 2	" - 1070
3	GUIDE PIN GOLD	202514 - 1	" - 1025
4	GUIDE PIN CAD.	200833 - 4	" - 1015
5	GUIDE SOCKET GOLD	202512 - 1	" - 1030
6	GUIDE SOCKET CAD	200835 - 4	" - 1020
7	#16 - #18 PIN	200336 - 1	" - 1045
8	#16 - #18 SOCKET	200333 - 1	" - 1050
9	PIN HOOD EXTERNAL	201390 - 5	" - 1065
10	CONNECTOR BLOCK BIN	200277 - 4	- 1000
11	SINGLE WIDTH MODULE COMPLETE, LESS CONNECTOR		1440 - 4100
12	NIM CRATE		



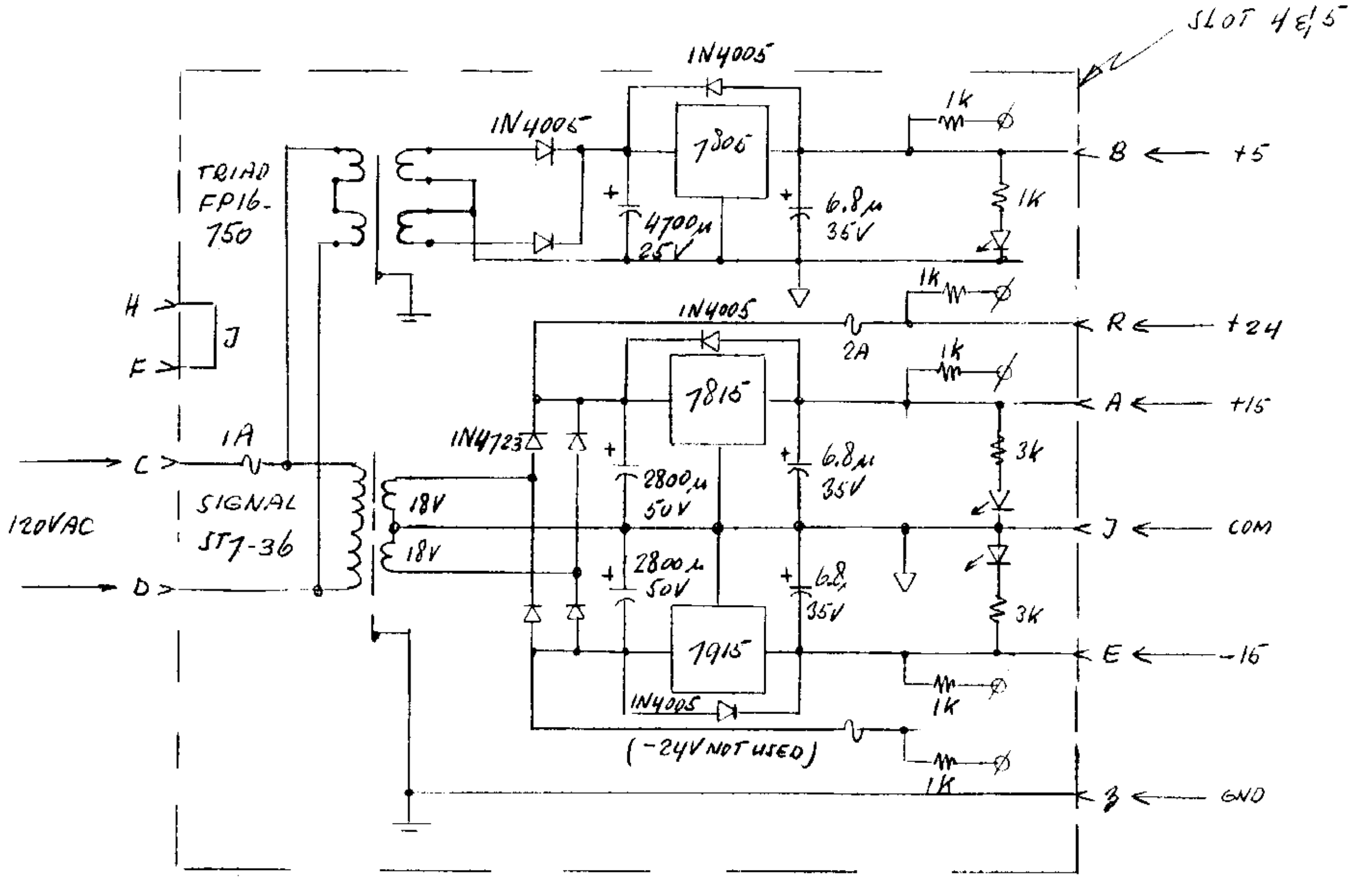
NIM - DETAILS

9

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	EED BS	MTF/SSC		

SUBJECT	NAME		
MTF DUMPSWITCH 10,000A, 1000V DC CONTROL POWER SUPPLIES	A.T. VISSER		
	DATE 10/23/89	REVISION DATE 8/28/90	WFJ

ATV061489MTF



FERMILAB ENGINEERING NOTE

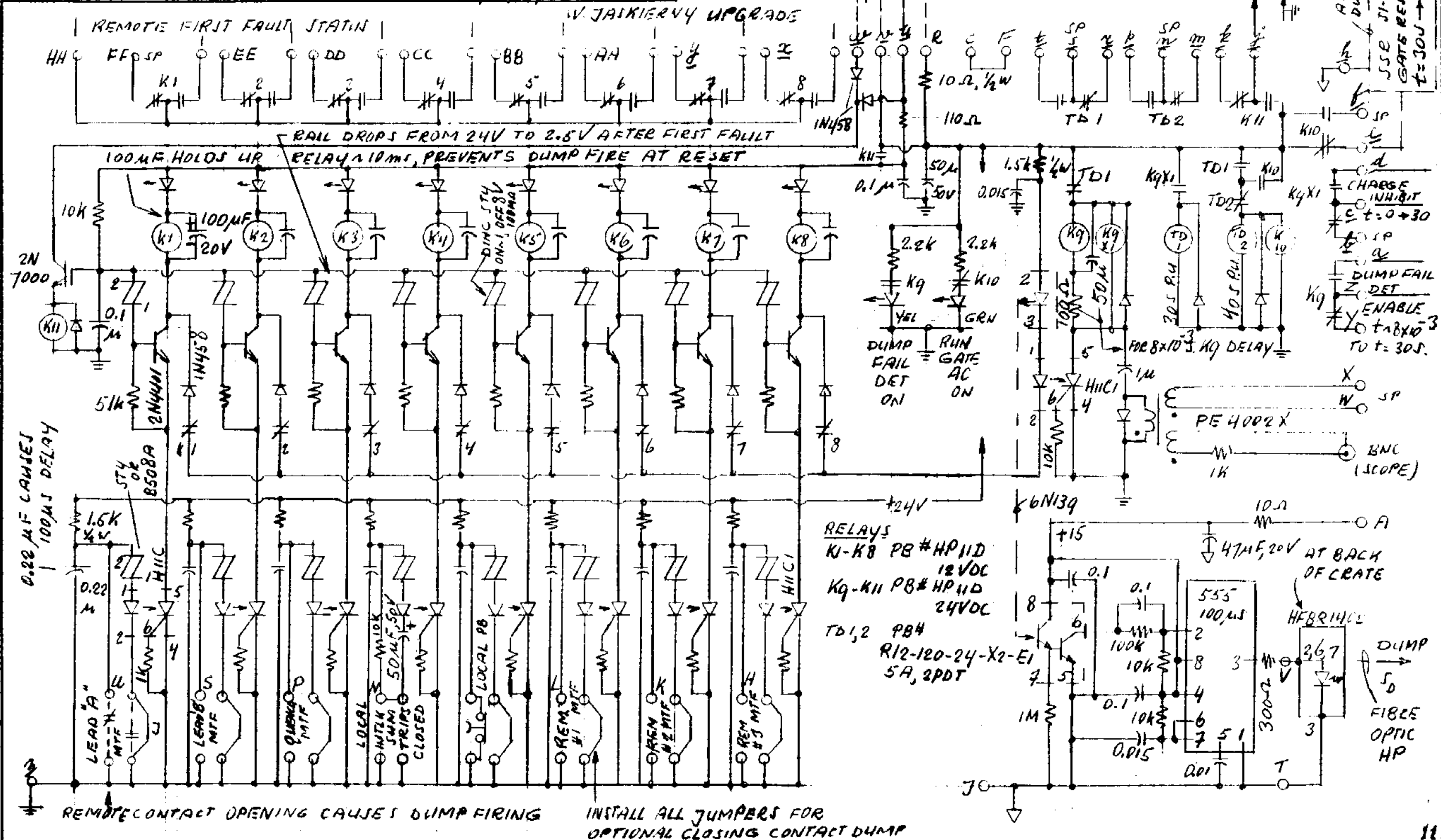
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED - BS	MTF/SSC		

SUBJECT: MTF DUMPSWITCH, 10,000A/1000V
DUMP PULSE DISTRIBUTION, TIMING, FIRST FLT LATCH

NAME: A.T. VISSER

DATE: 9/24/89 REVISION DATE: 8/28/90 12/90

#ATV061489MTF



12/90

FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED-BJ	MTF/SSC		

SUBJECT: MTF DUMPSWITCH, 10000A/1000V DUMP FAILURE DETECTOR

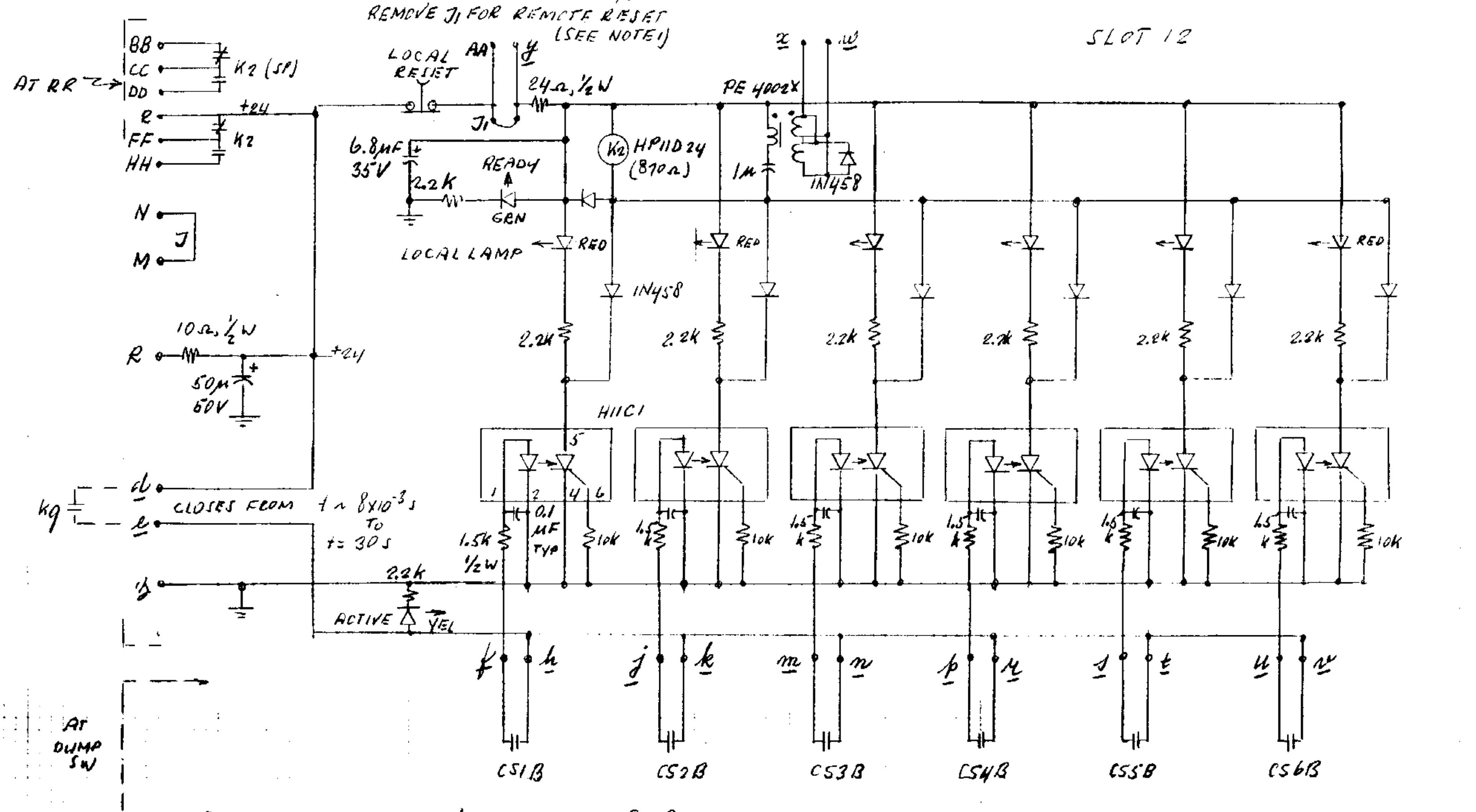
NAME: A.T. VISSER

DATE: 9/20/89 REVISION DATE: 3/28/90

#ATV061489MTF

WFJ

NOTE: REMOTE RESET OF A DUMPFAILURE IS NOT RECOMMENDED. CHECK SCR'S S1-S6 BEFORE RESET



CS'S PICK UP ~ 150A

CIRCUIT ENABLED FROM ~ 8 ms → 30 SEC AFTER DUMP PULSE

12

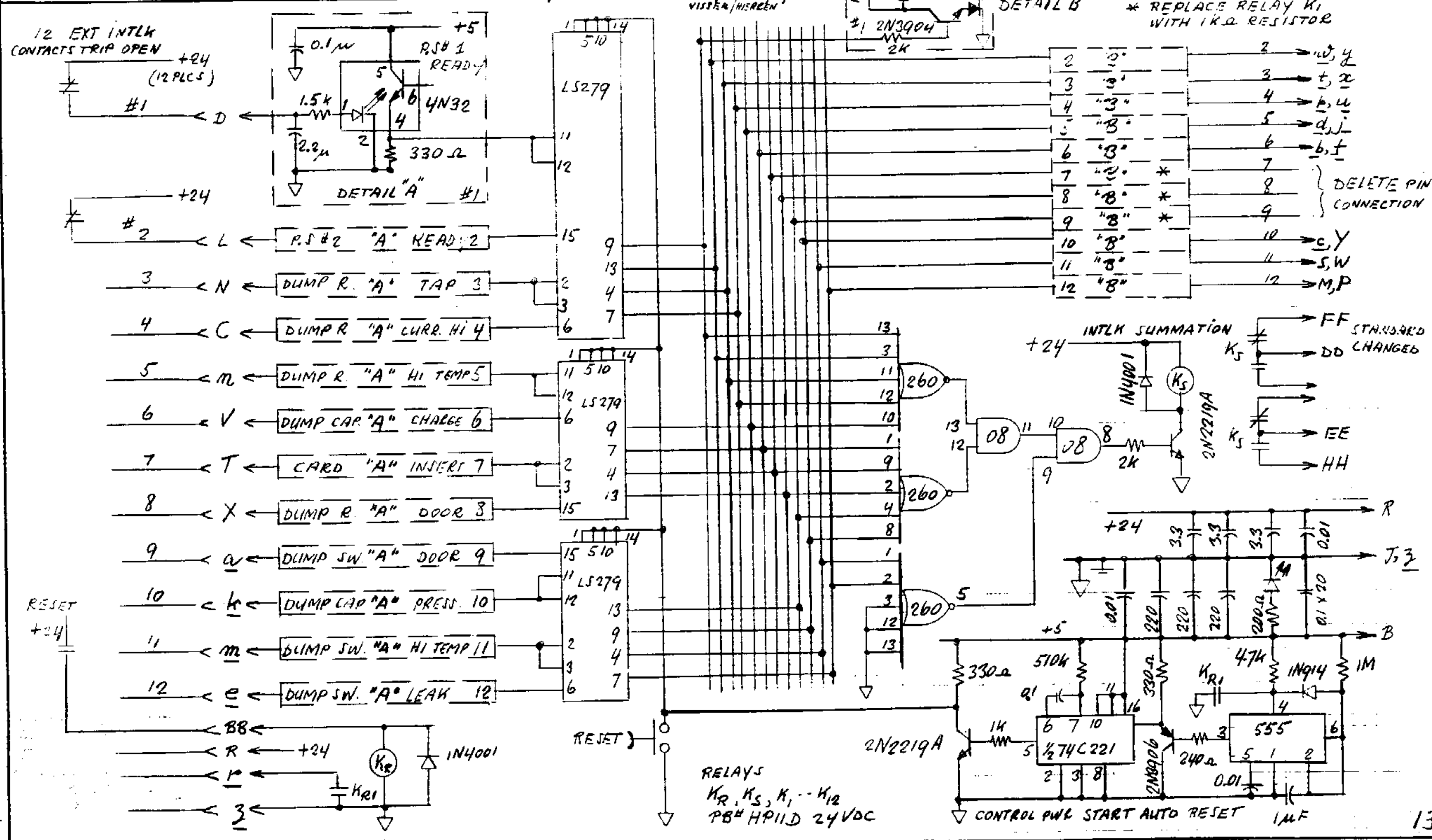
FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	EED	MTF	G TOOL	

SUBJECT: MTF DUMPSWITCH, 10,000A/1000V INTERLOCK SUMMATION, 12 CHANNEL

NAME	
A.T. VISSER	
DATE	REVISION DATE
12/20/89	8/ /90

DRW# ATV061489MTF
(REF. 5000A QSW DRW# 2789-EC 172034) VISSER/HEREEN

SLOT 7



13

37

12/90

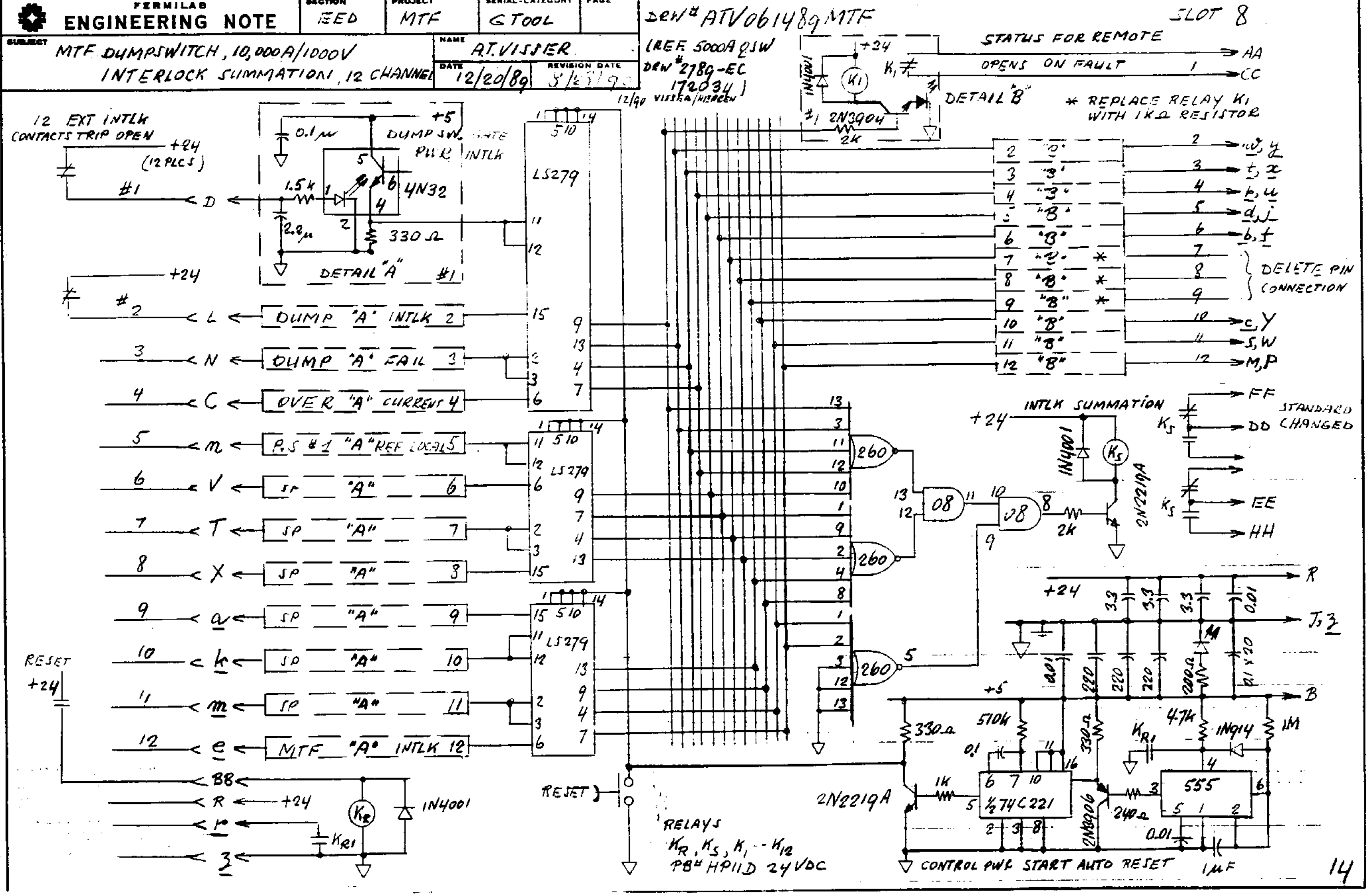
FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED	MTF	GTOOL	

SUBJECT: MTF DUMPSWITCH, 10,000A/1000V INTERLOCK SUMMATION, 12 CHANNEL

NAME: A.T. VISSER

DATE: 12/20/89 REVISION DATE: 3/25/90



12/90

NATIONAL ACCELERATOR LABORATORY
ENGINEERING NOTE

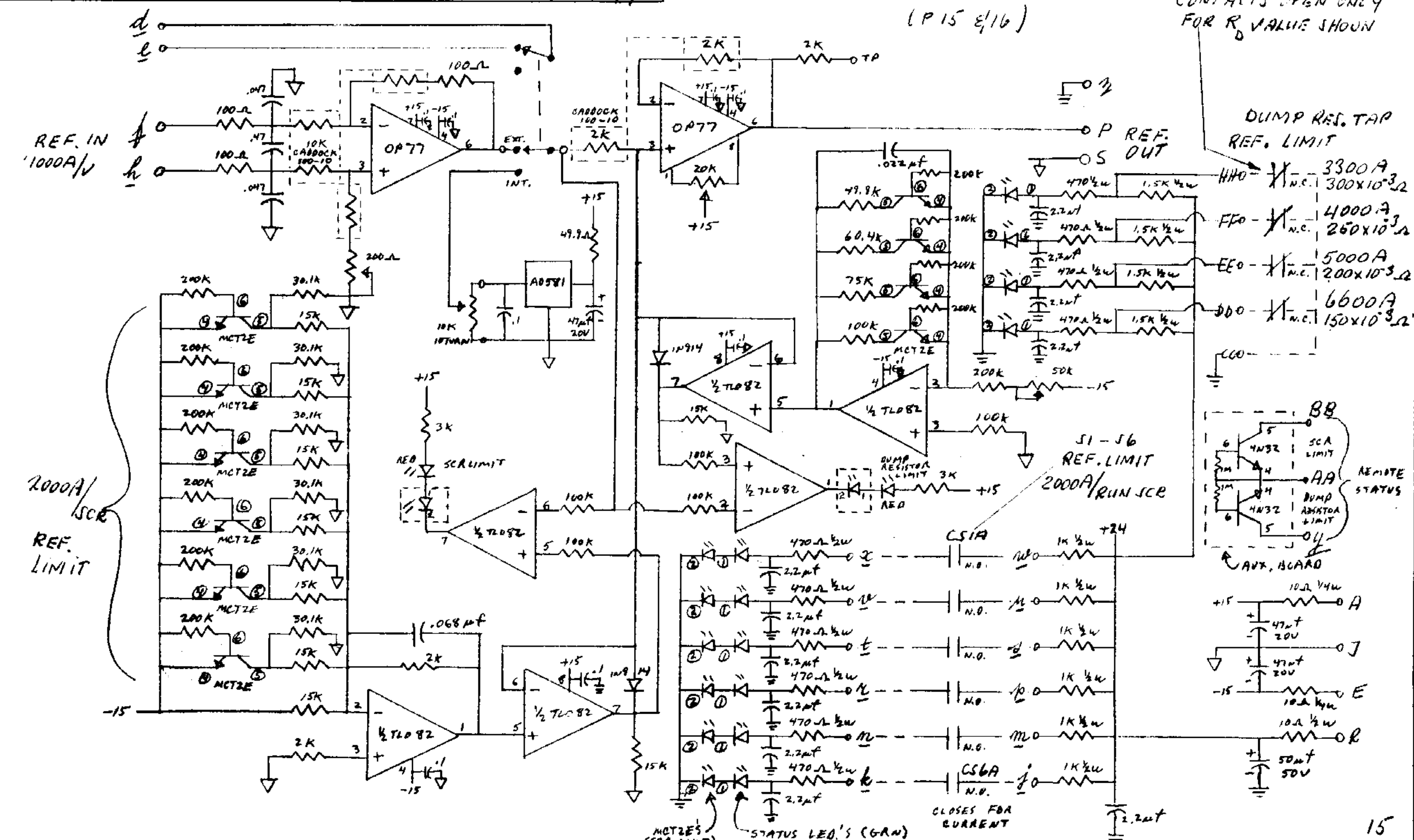
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
RD/EES	MTF 10KA P.S		

SUBJECT: MTF DUMPSWITCH 10,000A/1000V P.S. REFERENCE VOLTAGE LIMITER

NAME: W. JASKIERNY

DATE: 16 AUG 89 — REVISION DATE: 8/28/90

#ATV061489MTF



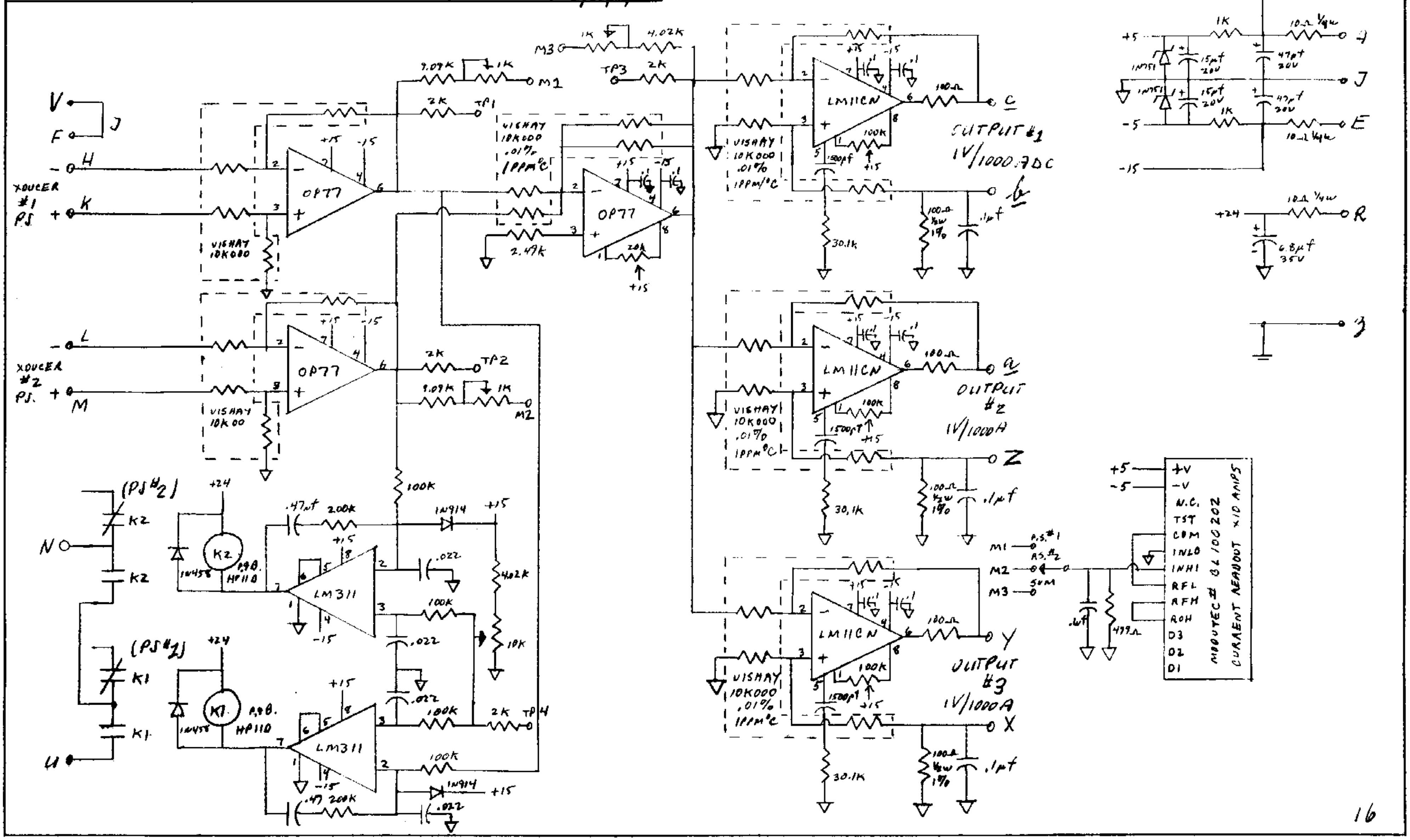
NATIONAL ACCELERATOR LABORATORY
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
AD/EES	MTF 10KA P.S.		

SUBJECT: MTF DUMPSWITCH 10,000A/1000V
P.S. TRANSDUCTER SUMMATION

NAME: W. JASKIERNY
DATE: 17 AUG 89
REVISION DATE: 8/28/90

ATV 061489 MTF
SLOT 1 & 2
PAGE 15 & 16



FERMILAB ENGINEERING NOTE

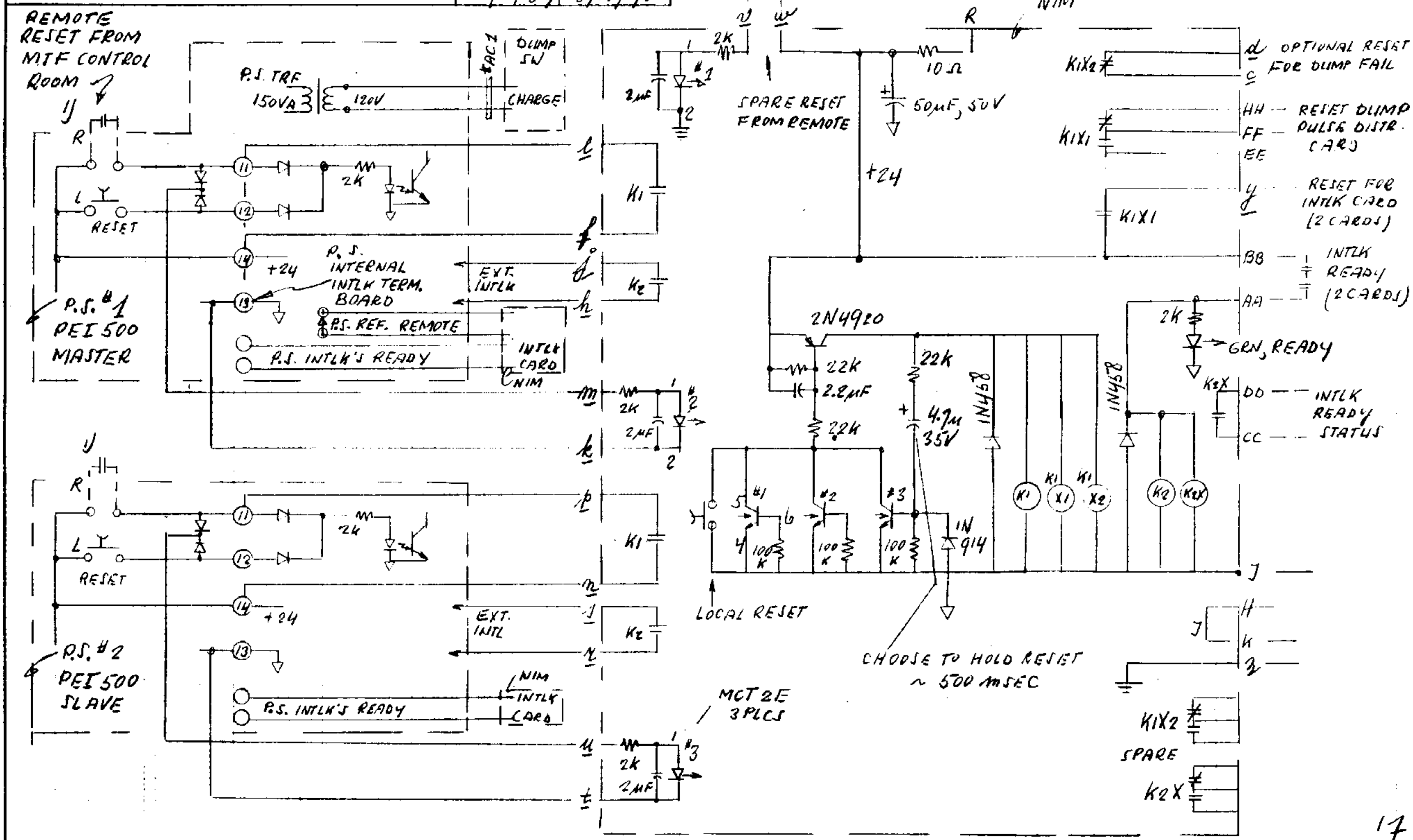
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EE0 8J	MT17/SSC		

SUBJECT: MTF DUMPSWITCH 10,000A, 1000V
P.S. RESET AND INTLK CONTROL

NAME: A.T. VISSER

DATE: 11/1/89 REVISION DATE: 8/28/90

ATV 061489 MTF



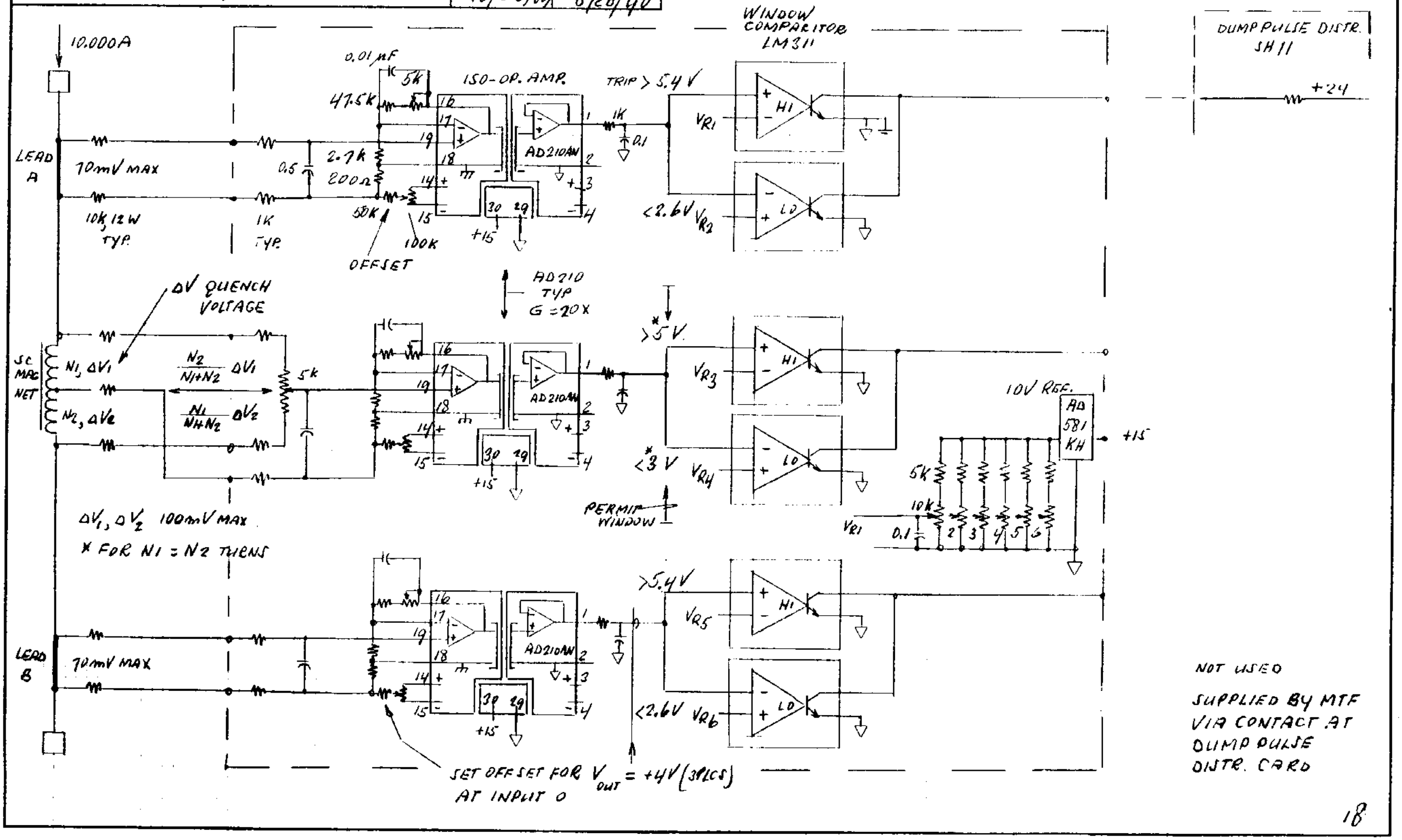
FERMILAB **ENGINEERING NOTE**

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED BS	MTF/SSC		

SUBJECT: MTF DUMPSWITCH 10,000A 1000V
LEAD VOLTAGE AND QUENCH DETECTOR

NAME: A.T. VISSER
DATE: 10/23/89 REVISION DATE: 8/28/90

ATV06148g MTF



18

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED - BS	MTF		

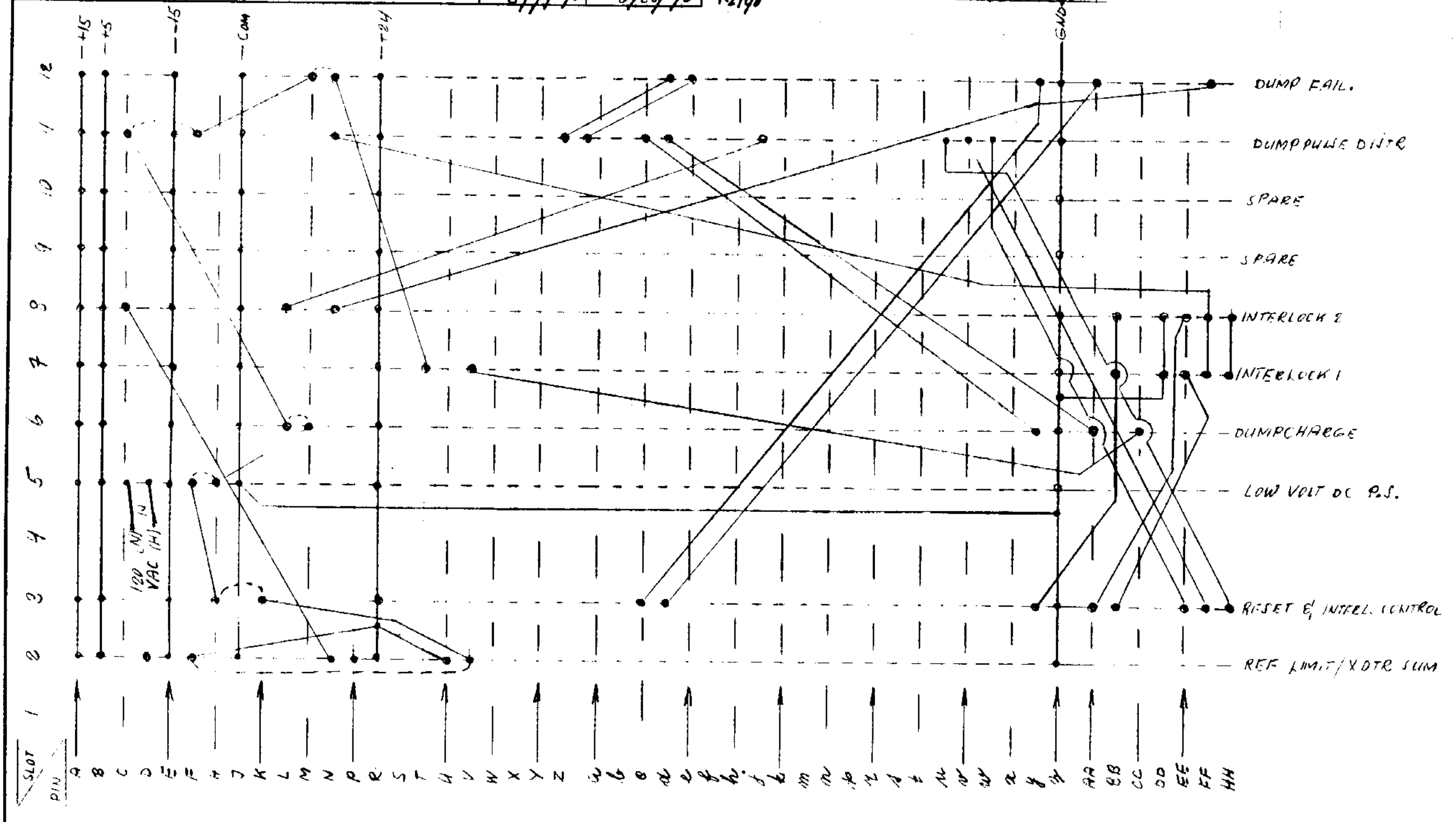
SUBJECT: MTF DUMP SWITCH 10,000A/1000V INTERNAL CRATE WIRING

NAME: A.T. VISSER

DATE: 5/7/90 REVISION DATE: 8/28/90

#ATV061489MTF

12/90



FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED-BS	MTF		

SUBJECT: MTF DUMPSWITCH 10,000A/1000V CONTROL WIRING PLAN

NAME: A.T. VISSER

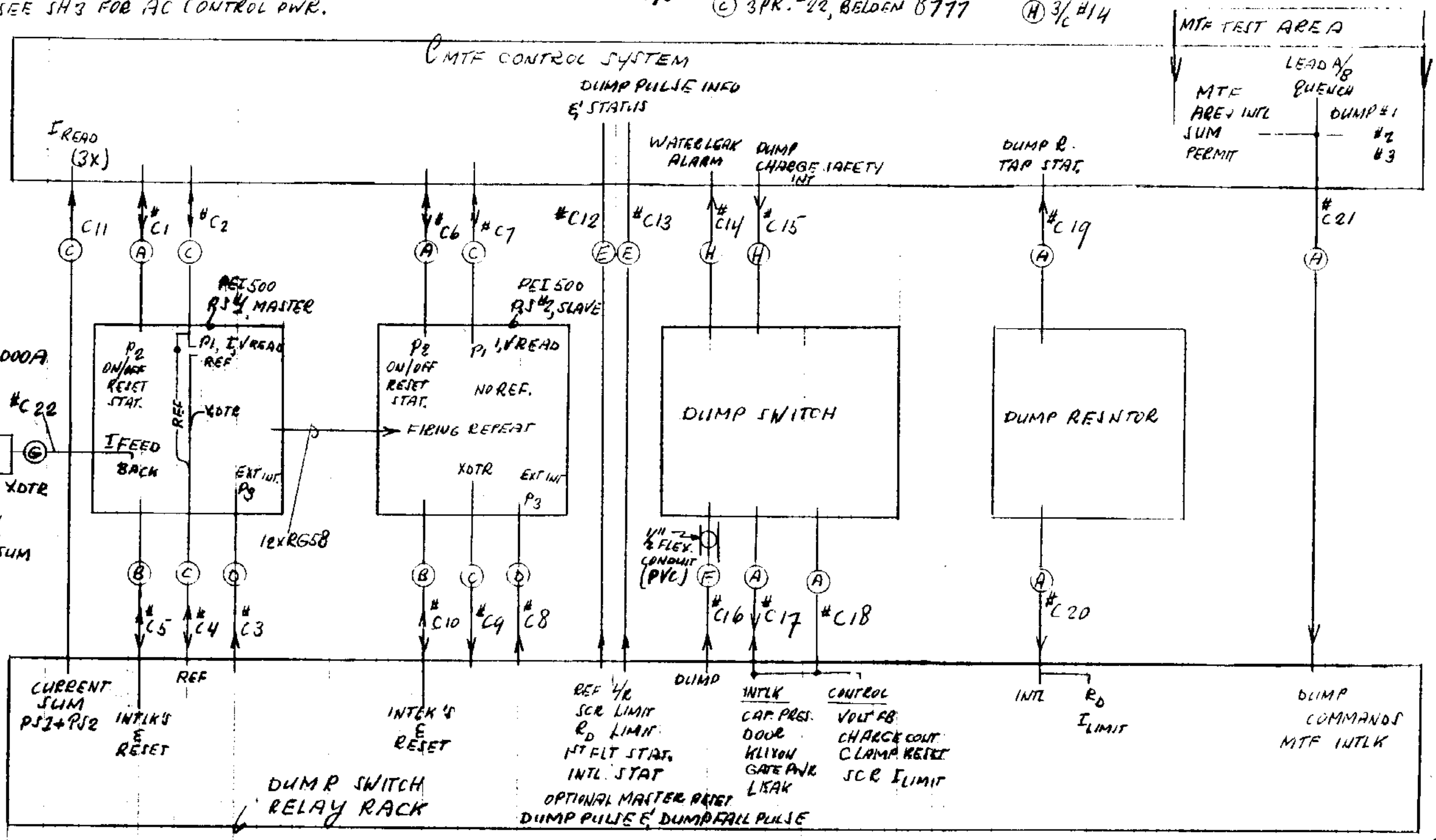
DATE: 5/25/90 REVISION DATE: 8/28/90

12/90

#ATV061489MTF

Ⓐ 12 PR #22 BELDEN 9768
Ⓑ 6 PR #22, BELDEN, 8778
Ⓒ 3PR. #22, BELDEN 8777
Ⓓ 3/C #16
Ⓔ 19 PR, SH. #22, # 1170-0200
Ⓕ HP FIBRE OPTIC
Ⓖ TWINAX
Ⓗ 3/C #14

SEE SH3 FOR AC CONTROL PWR.



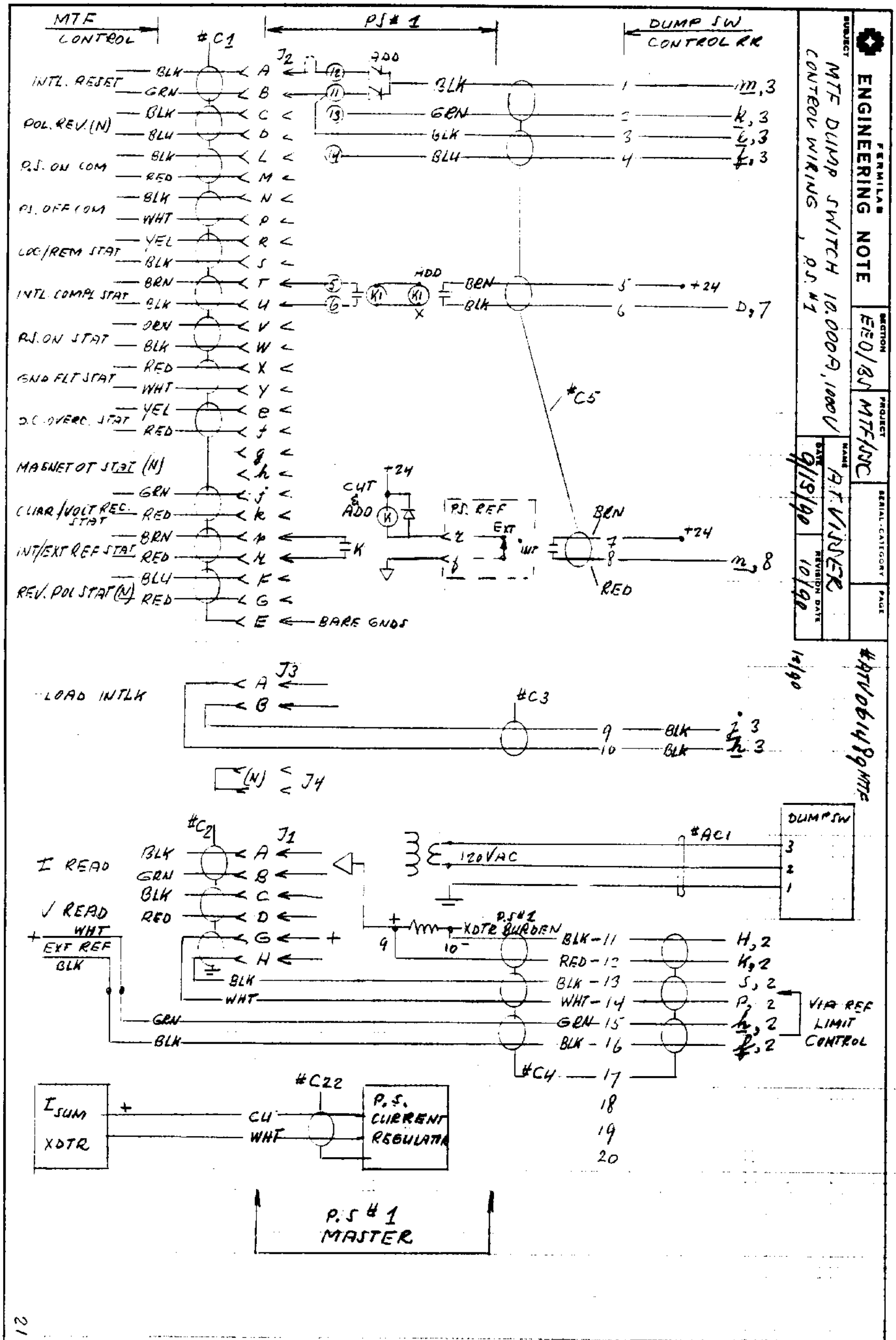
12/90

FERMILAB ENGINEERING NOTE

SUBJECT: MTF DUMP SWITCH 10,000A, 1000V CONTROL WIRING, P.S. #1

SECTION: EE0/BJ | PROJECT: MTF/NC | NAME: A.T. VINER | DATE: 9/18/90 | REVISION DATE: 10/90

#ATV061490 MTF



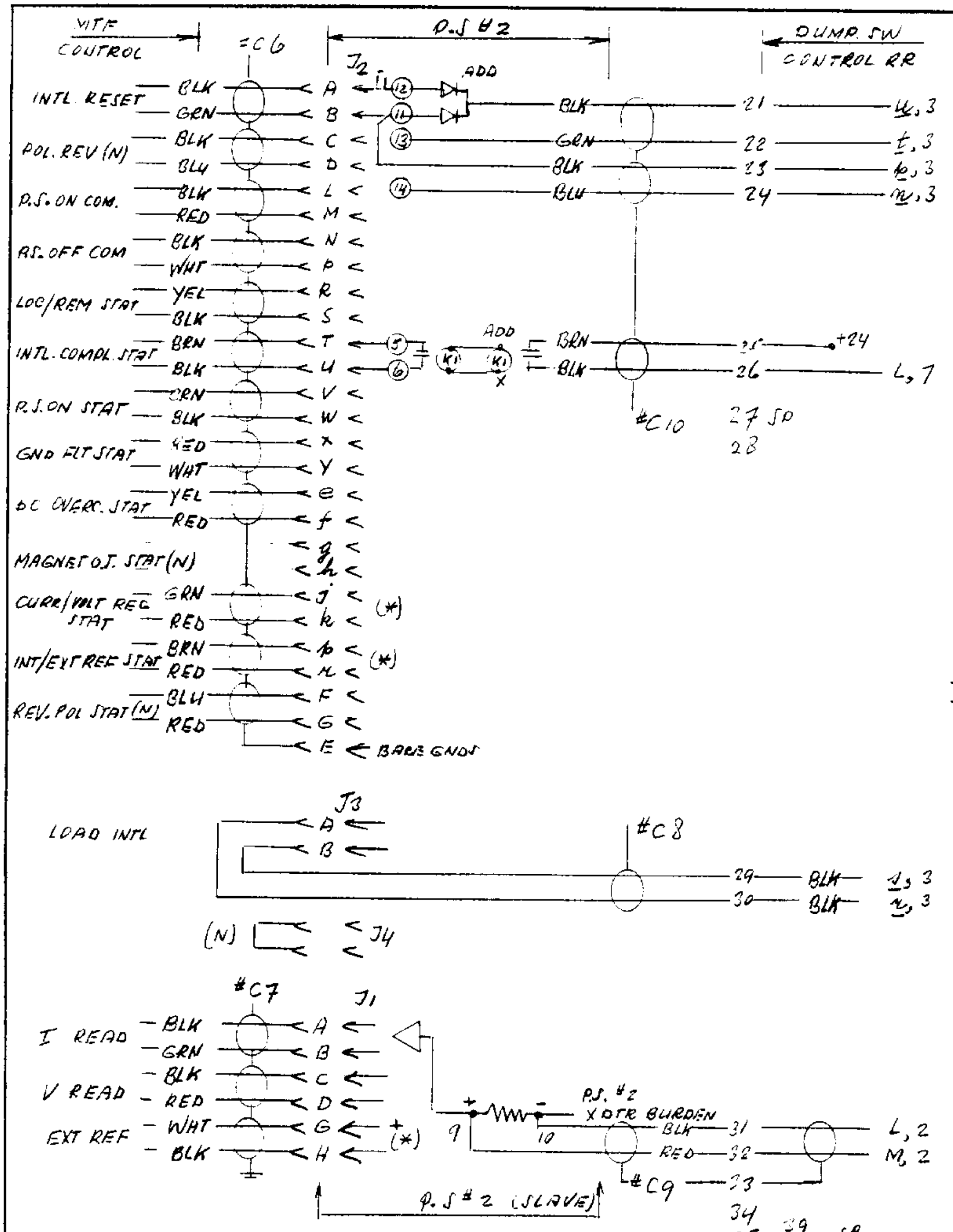
12/90

FERMILAB ENGINEERING NOTE

SUBJECT: MTF DUMP SWITCH, 10,000A, 1000V CONTROL WIRING, PS#2

SECTION: EED/BS | PROJECT: MTF/NC | NAME: A.T. VINGE | DATE: 9/13/90 | REVISION DATE: 10/90

#ATV061489MTF



(N) NOT USED

(*) NOT MEANINGFULL, SLAVE PS#2 FIR. CIRCUITS REPLACED WITH REPEATERS
I/V READ OF REG IS USED FOR MTF READOUT

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FERMILAB **ENGINEERING NOTE**

SUBJECT: MTF DUMPSWITCH 10,000A, 1000V CONTROL WIRING

SECTION: EED/SS | PROJECT: MTF/SSC | SERIAL-CATEGORY: | PAGE:

NAME: A.T. VISSER | DATE: 9/13/90 | REVISION DATE: 10/90

MTF CONTROL → ← DUMP SW. RR

#C11

MTF CONTROL	Wire	Terminal	DUMP SW. RR
		40	
I_{SUM} READ #1 1000A/V (+)	BLK	41	c, 2
	RED	42	b, 2
I_{SUM} READ #2 1000A/V (+)	BLK	43	a, 2
	WHT	44	z, 2
I_{SUM} READ #3 1000A/V (+)	BLK	45	y, 2
	GRN	46	x, 2

#C12

MTF CONTROL	Wire	Terminal	DUMP SW. RR
MASTER CONTROL EXT REF STAT	BLK	47	d, 2
	RED	48	e, 2
RUN SCR ON FAIL I_{LIMIT} STAT	BLK	49	BLK — BB, 2
	WHT	50	WHT — AA, 2
DUMP RES TAP I_{LIMIT} STAT	BLK	51	WHT — AA, 2
	GRN	52	GRN — y, 2
P.S 1 READY STAT	BLK	53	AA, 7
	BLU	54	CC, 7
P.S. 2 READY STAT	BLK	55	w, 7
	YEL	56	y, 7
DUMP R TAP WRONG STAT	BLK	57	t, 7
	GRN	58	x, 7
DUMP R CURR HI STAT	BLK	59	k, 7
	OR	60	m, 7
DUMP R TEMP HI STAT	RED	61	d, 7
	WHT	62	f, 7
DUMP CAP CHARGE LOW STAT	RED	63	b, 7
	GRN	64	f, 7
DUMP CAP. PRESS HI STAT	RED	65	c, 7
	BLU	66	Y, 7
DUMP SU TEMP HI STAT	RED	67	S, 7
	YEL	68	W, 7
DUMP SW LEAK STAT	RED	69	M, 7
	BRN	70	P, 7
DUMP SW GATE PWR STAT	RED	71	AA, 8
	OR	72	CC, 8
DUMP INTL STAT	GRN	73	w, 8
	WHT	74	y, 8
DUMP FAIL STAT	GRN	75	t, 8
	BLU	76	x, 8
P.S. OVERC AT MASTER CONTROL HI STAT	GRN	77	p, 8
	YEL	78	m, 8
P.S. 1 REF LOCAL STAT	GRN	79	d, 8
	BRN	80	b, 8
MTF INTLK SUM STAT	GRN	81	M, 8
	OR	82	P, 8
ALL INTLK'S READY STAT	WHT	83	DD, 3
	BLU	84	CC, 3

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FERMILAB ENGINEERING NOTE

SUBJECT: MTF DUMP SWITCH, 1000 A, 1000 V CONTROL WIRING

SECTION: EED/ES | PROJECT: MTF/SSC | SERIAL-CATEGORY: | PAGE:

NAME: A.T. VISSER | DATE: 9/13/90 | REVISION DATE: 10/90

ATV/061489 MTF

MTF CONTROL → | ← DUMP SW CONTROLER

C13

MTF control		Wire	Terminal	Dump SW controler
LEAD "A" 1st FLT STAT		BLK	85	HH, 11
		RED	86	FF, 11
LEAD "B" 1st FLT STAT		BLK	87	
		WHT	88	EE, 11
QUENCH 1st FLT STAT		BLK	89	
		GRN	90	DD, 11
INTL. 1st FLT STAT		BLK	91	
		BLU	92	CC, 11
LOCAL P.B. DUMP 1st FLT STAT	5	BLK	93	
		YEL	94	BB, 11
MTF REM #1 1st FLT STAT		BLK	95	
		BRN	96	AA, 11
MTF REM #2 1st FLT STAT		BLK	97	
		OR	98	y, 11
MTF REM #3 1st FLT STAT		RED	99	
		WHT	100	x, 11
		RED	101	
		GRN	102	
	10	RED	103	
		BLU	104	
		RED	105	
		YEL	106	
		RED	107	
		BRN	108	
		RED	109	
		OR	110	
		GRN	111	
		WHT	112	
	15	GRN	113	
		BLU	114	
		GRN	115	
		YEL	116	
DUMP FAIL PULSE FOR LOCAL USE		GRN	117	+ x, 12
		BRN	118	w, 12
DUMP PULSE FOR LOCAL USE		GRN	119	+ W, 11
		OR	120	X, 11
OPTIONAL REM. RESET AT MASTER CONTROL (CLOSING CONTACT)	19	WHT	121	v, 3
		BLU	122	w, 3

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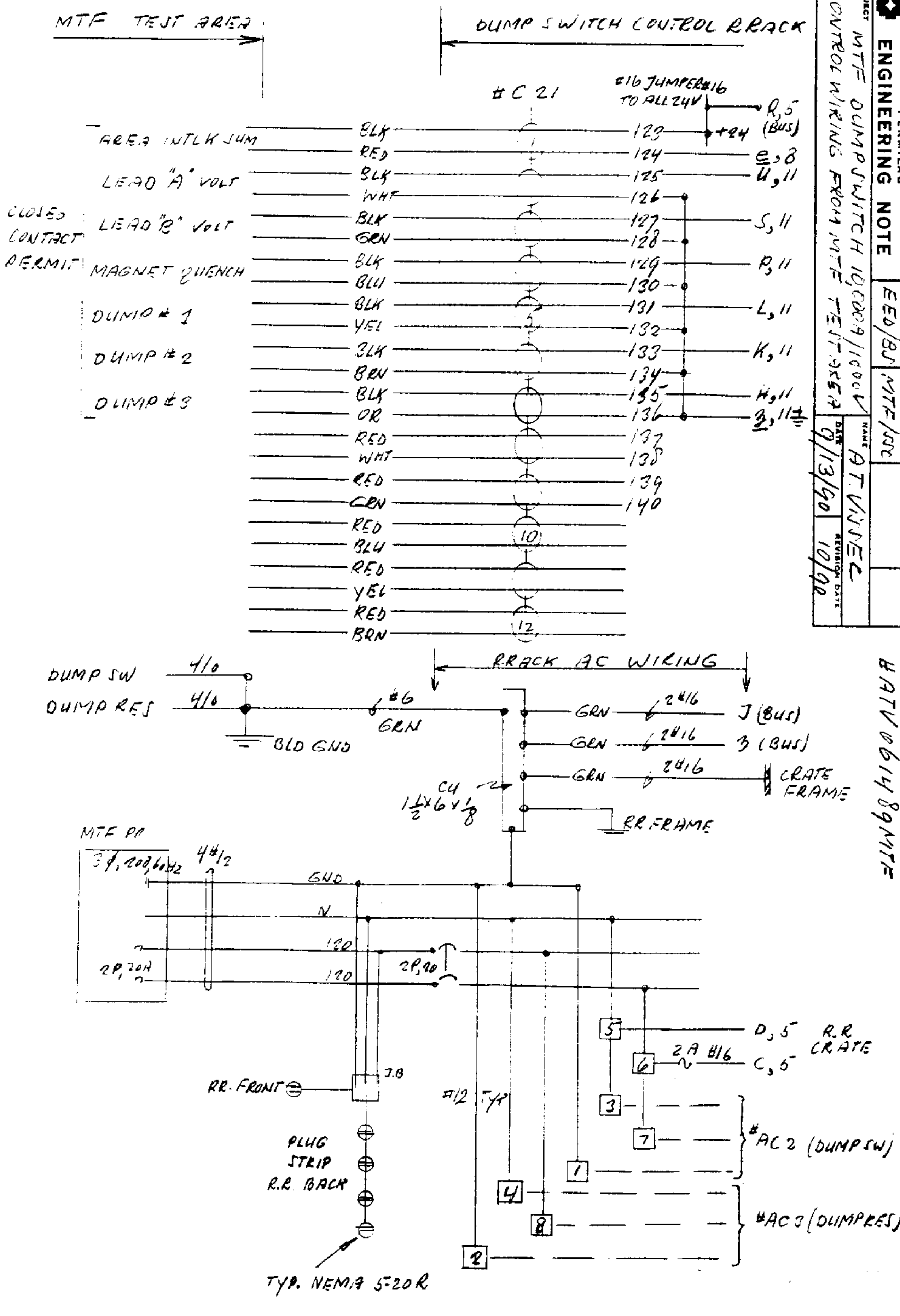
FERMILAB ENGINEERING NOTE

SUBJECT: MTF DUMP SWITCH 10,000A/1000V CONTROL WIRING FROM MTF TEST AREA

SECTION: EED/BJ | PROJECT: MTF/SSC | SERIAL-CATEGORY: | PAGE:

NAME: A.T. VISSEL | DATE: 9/13/90 | REVISION DATE: 10/90



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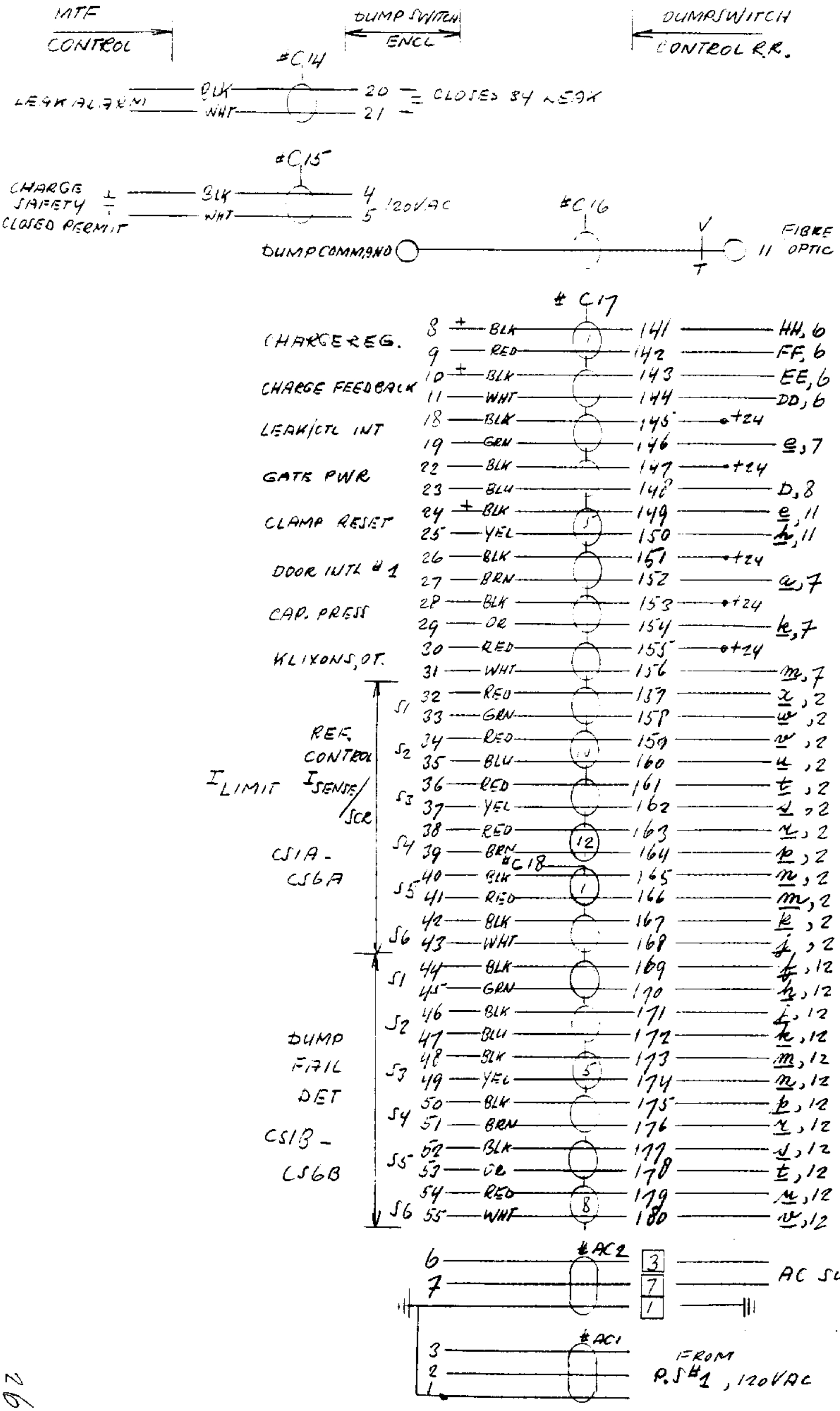

FERMILAB ENGINEERING NOTE

SUBJECT: MTF DUMPSWITCH 10,000A/1000V CONTROL WIRING, DUMPSWITCH

SECTION: EED-89 | PROJECT: MTF/SNC | NAME: A.T. VISSER | DATE: 9/13/90 | REVISION DATE: 10/90

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FERMILAB ENGINEERING NOTE

SUBJECT: MTF DUMPSWITCH 10,000A/1000V CONTROL WIRING, DUMPRESISTOR

SECTION: EED/ES

PROJECT: MTF/SSC

NAME: A.T. VISSER

DATE: 9/13/90

REVISION DATE: 10/90

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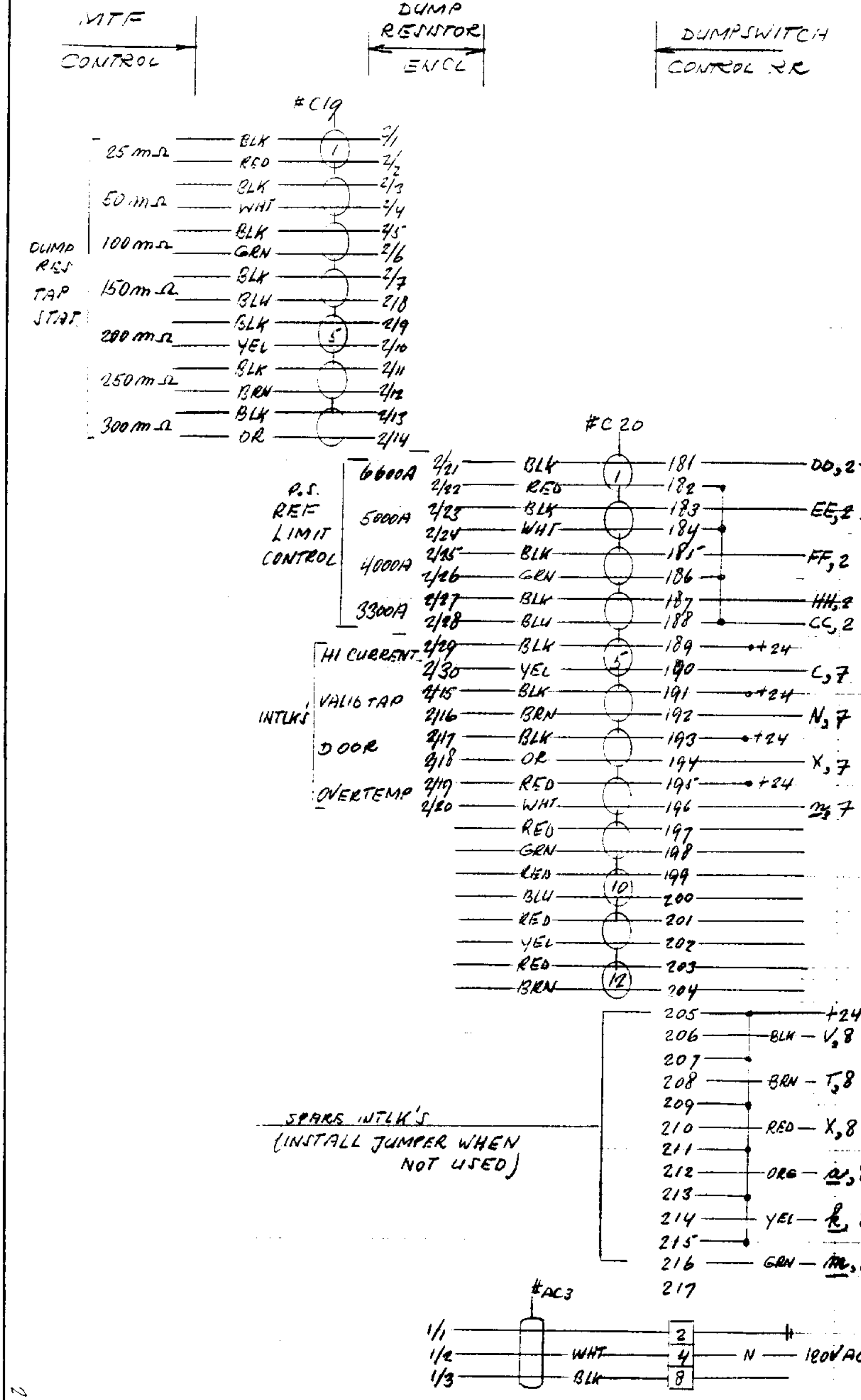

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FERMILAB **ENGINEERING NOTE**

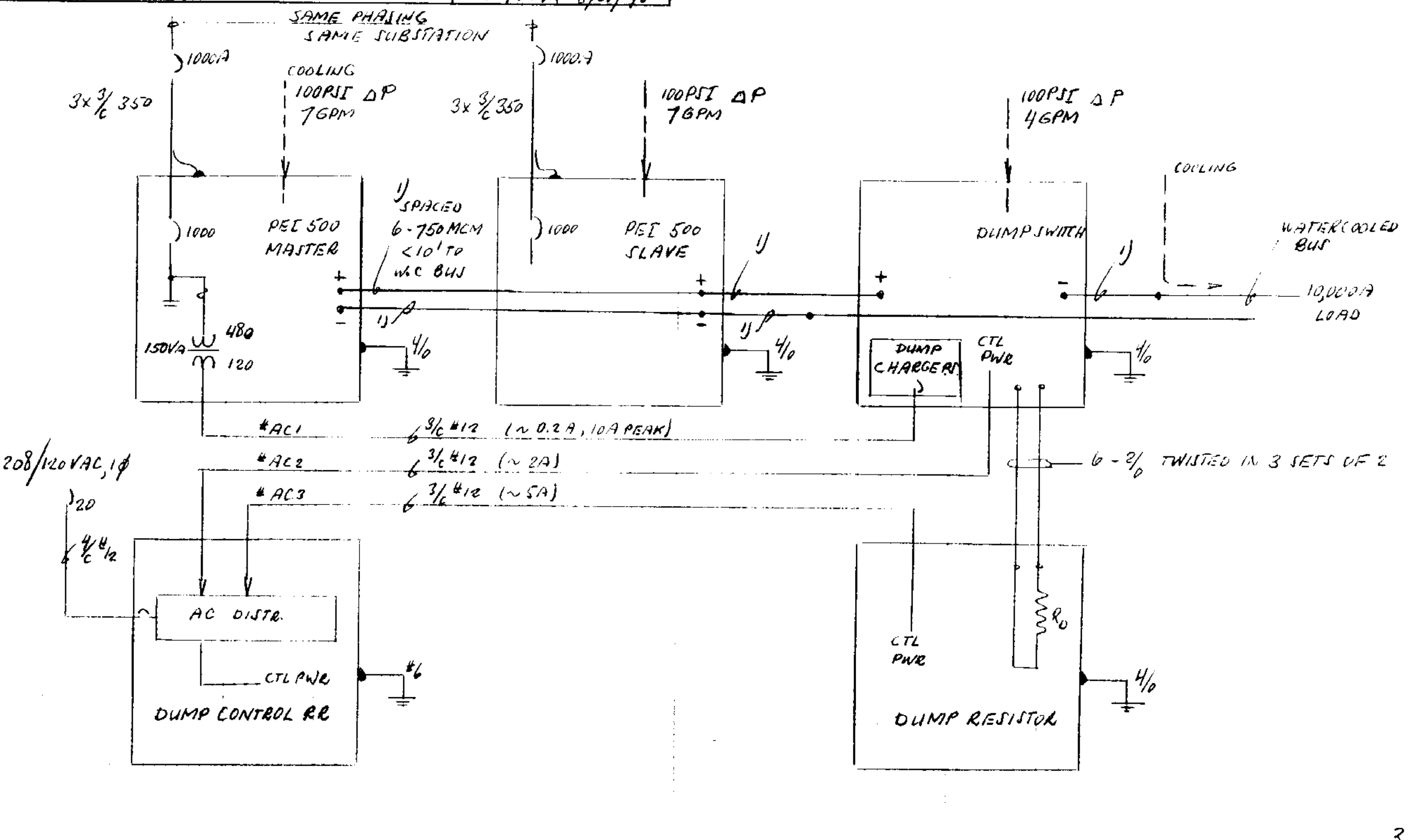
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
EED/BS	MTF/SSC		

SUBJECT: MTF DUMP SWITCH 10,000A, 1000V
ELECTRICAL POWER AND COOLING PLAN

NAME: A.T. VISSER

DATE: 10/27/89 REVISION DATE: 8/28/90

ATV061489MTF



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